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All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of January, March, May or November as the case may be. Subsequent delivery may be too late for insertion.

The Library.

In the full catalogue of the Library, published in our brochure of September, were included the titles of such papers in journals received as bear upon any subject within the purview of the Institution. Such titles are not included in the intermediate lists given in our several parts, where, as below, the journals received are acknowledged in single entries.

There are some slight corrections to be made in the brochure-catalogue, viz., the relegation to right alphabetical positions of the entries under HANDLIRSCH, MCLAUGHLIN and RUSSIA: the correction of references to papers by Messrs. HUNTLEY and JOHNSON as below, pp. vii, viii, and the addition of pp. 1192, 1193 to that by Prof. LEBEDEV, whilst the title of Prof. LEWES' second article should read :—The Chemistry of the " Cracking " of Heavy Oils.

The attention of such of our members as are authors is directed to the absence of their works from the Library, (with some exceptions), and we shall be particularly thankful for gifts of treatises on special branches of technology, and for separate copies of papers contributed to other Institutions and to journals, either in past or future.

ADDITIONS TO THE LIBRARY.

ANREP, A., jun. Enquête sur les Tourbières et l'Industrie de la Tourbe en Canada durant la saison 1909–10. (annexées, A. Larson, sur le procédé de carbonisation humide, 1908, et — Ekelund, une solution du problème de la tourbe, 1900). *Canada Dep. Mines, Mines Branch, Rep.* no. 196 (Bulletin no. 4) Ed. ii. 1913.

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Williams, M. Y. The Ordovician Rocks of Lake Timiskaming. *Canada Geol. Surv., Museum Bulletin*, no. 17. 1915.

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North of England Institute of Mining and Mechanical Engineers.
North Staffordshire Institute of Mining and Mechanical Engineers.
Oil Age.
Oil and Colour Trades Journal.
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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

The Institution has recently lost two notable members in a single week, Sir Thomas B. Bowring on the 18th October, as mentioned by the President in opening the second session of the Institution on the following day, and Prof. Vivian B. Lewes on the 23rd.

Sir Thomas Benjamin Bowring, who passed away in the sixty-ninth year of an active and useful life, was the head of the great shipping firm of C. T. Bowring & Co., Ltd., who for some twenty-five years have been extensively connected with the transport of petroleum in bulk.

His debut in commercial life was made in 1865 in the offices of Messrs. A. Howden & Co., London, and at the age of twenty-three he became a partner (in succession to his father) in C. T. Bowring & Co., Ltd., of Liverpool. Subsequently he proceeded to New York as partner in the United States branch of the firm, Messrs. Bowring & Archibald, residing there for more than twenty years. Some particulars of their fleet of oil boats are given by Mr. Barringer in his account of the evolution of the tankship in our last volume, p. 290.

Sir Thomas was also chairman of the English and American Shipping Co., Ltd., vice-chairman of the Eagle Oil Transport Co., Ltd., and director, until debarred from active business, of several Companies connected with the production and transport of petroleum and its products. He was knighted in 1913, and took an active part in the foundation of this Institution, recently presenting its library with a valuable series of handbooks on various branches of science and technology.

In Prof. Lewes we have lost one of our most valued supporters, and his sudden removal, in the full tide of most useful vigour, will be deeply felt, not only in the wide circle of his direct acquaintance, and the far more extensive range of his many crowded audiences, but in the councils of the nation, both at the present critical juncture, and in the future tranquillity to which we look forward.

The Inventions Branch of the Ministry of Munitions, and especially its Chemical Committee (of which he was Chairman), will sorely

miss his clear insight into difficult problems, and his lucid exposition of results or methods of research.

By those who had the high privilege to be his intimate friends, he was regarded with much affection, as well as esteem for his unique talents, whilst in outer circles his infectious cheerfulness, vivacious humour, modesty in reference to his own achievements, generous appreciation of those of his compeers, simplicity of diction and wide range of information, led all who heard him to desire personal acquaintance with so charming an individual. Not the least element in this attractiveness was the fluency with which the most complex topics were discussed, and elaborate formulæ, &c., produced on the blackboard, without any reference to notes or hesitancy of hand or speech.

Born in 1852, and losing his father (who was a surgeon) in early youth, he was educated, under the charge of his uncle, the distinguished philosopher G. H. Lewes, at University College School, London, and later in the College itself. At the age of 16, he became assistant to Prof. F. Barff, and two years subsequently to Prof. A. W. Williamson, then Chief Metropolitan Gas Examiner, at the Birkbeck Laboratory, of which he had charge for a time under Dr. C. Graham. He next undertook the management of Prof. Williamson's experimental works at Willesden, and in 1879 joined the staff at the Royal Naval College at Greenwich. Within a year he was appointed as Gas Examiner at the Cloth Fair testing-station of the City of London and in 1892 as Chief Gas Examiner for the Corporation. Meanwhile in 1888, he had accepted the chair of Professor of Chemistry at the Royal Naval College, which he held till the end of 1914.

Being long recognised as the foremost expert in matters relating to gas, he was one of the five honorary members elected by the Institute of Gas Engineers in 1903.

Besides being the author of several useful hand-books and larger works, he was one of the most popular lecturers at the Royal Society of Arts, delivering twelve series of Cantor Lectures, the Fothergill Lectures of last spring, and a course on Modern Munitions of War shortly after, appearing altogether over sixty times in the Society's Hall. He held three medals from the Society of Arts, besides others from the Gas Institute, the Society of Engineers, the Institute of Naval Architects, and the Gilchrist Educational Trust, of the original corps of lecturers for which, all men of the highest note, he was the last survivor. It was, in fact, for a lecture under that Trust, on "The Explosives used in the Great War," that he undertook, in opposition to medical advice, his final journey,

reaching Mold only to die, struck down with double pneumonia, and disappointing, for the only time in his career, the audience that had hoped to hear it.

A man of great vigour, indefatigable alike in thoroughness of study and in the physical labour necessary for the promulgation of its results, he had, some time back, when in poor health, expressed the hope of dying "in harness," and the wish was granted.

Prof. Lewes was twice married: he leaves, by his first wife, a son, Lieut. Edward Lewes, now in command of a submarine, and two daughters, married respectively to Capt. Hanson and Flight-commander Briggs; by his second wife, a daughter of Col. Lewis Jones, he leaves three young daughters.

His funeral at the Royal Naval College Cemetery, a fitting resting-place after his thirty-four years' connection with the College, was attended by many of the staff and by representatives of several Societies, Institutions and Companies, who realise that in the death of Vivian Byam Lewes, they have sustained an almost irreparable loss.

The sympathies of the members will be extended to Mr. E. B. Forbes on the loss of a second son in action on the French front; a third is still serving his country there.

We are aware that many of our members are engaged on duty to their country with the land forces, at sea, or in munition work, who have not yet communicated to us the requisite intimation for entry in this column. We shall be glad to have such information from them or their friends who may see this notice.

Mr. J. T. Armstrong is requested to favour the Secretary with his present address.

Dr. T. O. Bosworth's paper on the Tar Sands of Canada, postponed from the December meeting by reason of the author's detention in America, and subsequently set down for March, is necessarily deferred again by his finding it necessary to remain abroad till next winter, visiting South America, and effecting further investigations in Northern Canada in the interval.

Mr. William Calder went to South Russia at the end of July.

Mr. J. A. Child returned from Lobitos to this country in July, and is now 2nd Lieutenant in the 174th Company (Tunnelling), Royal Engineers.

Mr. T. R. H. Garrett, R.N., Armoured Car Division, is Chief Petty Officer.

Lieut. G. W. Halse, R.N.V.R., is working in connection with the Air Service.

Mr. D. L. Houghton is a 2nd Lieutenant in the 5th Middlesex, attached to the 7th London Regiment.

Mr. J. Kewley, formerly Manager of the Refinery of the Anglo-Egyptian oilfields at Suez, is now General Manager for the Asiatic Petroleum Co. at Portishead.

Our Acting Secretary, Mr. F. J. Palmar, is now 2nd Lieutenant in the 20th Middlesex Regiment.

Mr. F. G. Rappoport left for Burma at the end of September.

Mr. Francis Russell returned from Rumania in October.

Major J. J. Whitehead is in the 17th Battalion, Manchester Regiment.

The following series of papers will be read to the Institution in the coming year.

January 18th, Mr. Herbert Barringer on Oil Tank Storage.

February 15th, Mr. W. H. Manfield on Oil Shales, especially those of the Dorsetshire Kimmeridgian series.

March 21st, Dr. J. A. L. Henderson on Natural Gas.

April 18th, Mr. E. H. C. Craig on Oil Shales.

May 16th,

We are also promised a paper by Mr. J. W. Burford on the application of electrical power in oilfields, and anticipate the pleasure of hearing Dr. W. F. Hume on the petroleum industry of Egypt.

At some convenient time we intend to publish an account of refining in Rumania, by Mr. W. E. Guttentag, and a critical summary of recent geological literature on the Rumanian oilfields by Mr. F. W. Penny. These being, in the absence of their respective authors, "taken as read," will be open to subsequent discussion in our pages.

An elaborate series of reports is announced as in course of preparation by the Federal Trade Commission of the United States, "dealing with every phase of the production, transportation, refining, and marketing of crude petroleum and its refined products" in the United States. The first report will deal with the cost of transportation of crude oil by pipe-lines.

DINNER AND LUNCH CLUB
IN CONNECTION WITH THE INSTITUTION.

The formation of this Club was projected with the object of enabling members to dine together before each Meeting, and to lunch together a few days later, so that they might thus have the opportunity of informally discussing various subjects brought to their notice.

Members are entitled to introduce guests, on giving due notice to the Hon. Secretary.

As each person present pays for his repast, the Club subscription is a nominal one, only intended to defray the cost of printing and postage. It is at present fixed at five shillings per annum. More than thirty members have already joined the Club.

Sir BOVERTON REDWOOD has accepted the position of Chairman, and Mr. ARTHUR W. EASTLAKE that of Vice-Chairman, of the Club.

Mr Ashley Carter, of Dashwood House, New Broad Street, E.C., kindly acts as Hon. Secretary to the Club.

EDITORIAL.

En avant! In the remarks with which our perspicacious President opened the new Session, as reported a few pages below, he set forth concisely excellent reasons why the functions of the Institution, in place of being suspended, even partially, during the present critical period, should, if anything, be stimulated by consideration of their great importance to the national well-being.

Alike in peace or war, larger and larger supplies of crude oil are essential, and equally so are improvements in the preparation of the various products of which it is the primary source, and in the means of transport and utilisation adopted.

Whether contributing to the evolution of energy by direct combustion, or as efficiently, though less palpably, by its conservation through the use of lubricant preparations, petroleum and its many products constitute a large element in the national resources of the civilised world, and at the present time, when civilisation is threatened with extinction, and the world is menaced with reversion to barbarism, every assistance to the development of the petroleum industry, in any of its branches (but especially in military directions), tends to the preservation and improvement of civilisation.

Consequently the oil-prospector, the driller, the shipper, the refiner and the distributer are all helping in useful ways to promote national and universal welfare, as truly as those bearing arms on land or sea, or labouring in munition factories.

But just as, in civil life, the direction of energies is varied from time to time in accordance with contingencies, so, under the present combatant status, attention may justly be turned to special military requirements rather than to those of ordinary tranquil commerce.

The chemist, for example, may concern himself especially with the lighter hydrocarbons, the mechanician with improvements in motor-vehicles, the marine engineer with modifications in respect of either storage or propulsion, as conditioned by the requirements of navigation, and so on; whilst the oil-field specialists are necessarily limited in the choice of areas calling for their attention by accessibility by the enemy powers by regions of origin or routes of transport therefrom.

We find that through the solidarity of the complex conditions of modern life, even slight changes in production or consumption of any substance of common usage affect that not only of kindred matter, but of all possible surrogates, and these disturbances are

propagated like vibratory waves to regions that might have been supposed too remote for any perceptible effect. The old demonstration that game-keeping reduces the nitration of the surrounding arable land, through the comparatively short chain of owls-mice-humblebees-clover serves to illustrate the wide extent of the influence of apparently inconsiderable causes.

Under existing conditions, not only is the consumption of petroleum and its products enormously enhanced, but many oil-properties have been either destroyed, crippled or temporarily paralysed, largely reducing the output from those regions. Newly-discovered fields will require time for their development, even where capital can be obtained, and it is therefore the more important duty of proprietors to economise their existing stock, underground as well as above it, by arresting the enormous waste observable in many fields, not only in the escape of gas and oil at the surface, but in their subterranean dispersal by water admitted in the process of boring, or in the subsequent management of the wells. Ingenious devices for prevention of waste are of small use, if not at hand for immediate application. It may not be practicable to prevent the upward gush of gas, oil, or the usual mixture of the two, from acquiring high velocity, but the speedier its arrest, the slighter is the erosion of subterranean passages, in which the velocity obtained is a factor of much importance. Gas-flow will sometimes carry up impalpable dry powder from clays that when moist are tough and plastic, and sand-grains offer still less resistance to erosion of channels. Similarly with the access of water to the productive sands from either above or below: permanent mischief may be effected by brief delay in the application of remedial measures after the connection has been made. Only water under control of pumps should have access to possible oil-sands, and any discharge from deepseated water sands should be sealed off in advance from the overlying oil. In other words, prevention is better than cure.

Any progress, therefore, in the direction of reduced waste, involves (1) the selection from among the methods and plant at present devised, of those most suitable for the special character of each oilfield, and their adjustment to the particular nature of each well as far as this can be foreseen: (2) their presence on the ground ready for instant application when occasion arises: and (3) alert intelligence of the driller to perceive the approach of the said occasions, and apply the provided means as promptly as possible.

The last of these desiderata bears on the matter raised in a previous article, that of drilling logs. It is evident that the driller

will be much better able to foresee irruptions of gas, oil or water, if he has an accurate record of other wells in the field, and of the one in hand, and, in geological parlance, knows where he (i.e. the point of his bit) is, in relation to recognisable beds, whether important from an engineering point of view, as hard or soft, charged with fluids or impervious, compact or caving, or geologically useful as key-rocks, landmarks in the mass penetrated, and guides in forecasting further progress.

"Art hath no enemy but ignorance," saith the old Roman sage, and ignorance is the most deadly foe of technology, which is art in practical, as distinguished from æsthetic directions: in either, it is the control of natural forces to desired effects.

There are many points in which further investigation is necessary to ensure such control in such respect as petroleum. Dr. Glazebrook's admirable paper on viscosity, published in this issue, refers to several collateral matters on which more light is urgently needed, but can only be obtained by prolonged and accurate experiment. Minute errors of observation may result in serious mistakes when magnified into quantities for commercial handling. Accurate reading will not obviate errors inherent in instruments, either badly-designed or imperfectly constructed, and the most admirably-elaborated apparatus is useless (if not worse) in careless or inadequately-trained hands.

Besides this, there are, in some cases, natural conditions militating against useful observation: for instance, the effect, in flash-point determinations, of the reduced barometric pressure in elevated regions upon the evolution of inflammable gas. With refined oils of comparatively few admingled components, there is a recognised formula for correction to a standard pressure, but with a crude oil, of unknown but probably wider range of composition, the effect of reduced or enhanced pressure (generally the former) cannot be more than approximately estimated. No prophecy as to future discoveries in this (or any other) direction is safe, but it may be found practicable for laboratories at various elevations to be fitted with means of operation in air compressed to the normal standard, where requisite for special observations.

Space is lacking here even for a bare schedule of the many problems awaiting solution in our wide-ranging industry, but we propose to recur to the topic, and shall be glad of suggestions of points (of non-local character) requiring elucidation.

W. H. D.

Eighth General Meeting.

The first meeting of the second Session of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, 19th October, 1915, Sir Boverton Redwood, Bart., D.Sc., F.R.S.E., President, occupying the Chair.

The Members of Council present were Prof. J. Cadman, and Mr. Arthur W. Eastlake, and messages expressing regret for inability to be present had been received from Mr. Alfred C. Adams, Professor Lewes, Sir Thomas H. Holland, and Mr. T. C. Palmer.

The Hon. Secretary (Mr. Arthur W. Eastlake) announced that the following gentlemen had been elected :—

As Members :—George Thomas Holloway, Richard Gillies Neilson, Maurice Albion Ockenden, Francis Russell, Stephen Frank Stackard, and Charles T. Willans.

As Associate Members :—Luis de Florez, Robert Bertram Grey, Harold Edgar Keary, Richard Roy Lewer, John Edward Lloyd Strevens, Robert Reginald Thompson, and Carter White.

As Students :—Burton Dunglinson, Charles Walter Hodsdon, and Launcelot Owen.

As Associate :—James Solomon Blanckensee.

The President, in opening the proceedings, said that in the first place he desired to welcome the Members and their friends at the commencement of a new Session, for which he was much pleased to be able to state that a good programme had been arranged. Following the paper which was to be read at the present meeting, a very valuable communication, which was to be given with the authority and sanction of the Admiralty, would be read at the November meeting. It was contributed by Dr. R. T. Glazebrook, C.B., F.R.S., the Director of the National Physical Laboratory, together with Mr. Higgins and Mr. Pannell, who were responsible for the experimental work which was carried out. It would record the results obtained in an investigation having for its object the determination of the relation of viscosity to the rate of flow of oils through pipes. That was a subject in reference to which very little information was obtainable, and the data which would be supplied would be of the greatest service to those engineers who were engaged in the designing of plant for the piping of oils. At the December meeting, Dr. Bosworth

was to deal with the controversial questions raised at the discussion which took place on Mr. Cunningham Craig's paper during the last session, and he expected that another equally delightful illustration would then be given of the scope which geology afforded for forming not precisely concordant views upon given data. At a subsequent meeting another important paper was to be read on oil-tank storage by Mr. Herbert Barringer, who gave during the past session such an excellent account of the evolution of the oil-tank steamer; and later in the session Mr. Hardy Manfield would discourse on the utilisation of the oil shales of the Kimmeridge series. At some convenient date it was hoped to make arrangements for the discussion of the subject of oil-well logs, to which reference had been made in the Journal. A valuable contribution to that discussion had already been received from Mr. Wells, and he hoped that many others would be forthcoming, the subject being one of the greatest importance in relation to oilfield development work. The Institution was therefore commencing the session under excellent auspices. In that connection he desired to mention that the Honorary Editor, Mr. W. H. Dalton, to whom the Institution owed so much in connection with the conduct of the Journal, had prepared, at the suggestion of the Council, a brochure which gave information as to the origin, progress and purposes of the Institution. It was in process of being sent out, and every Member would receive a copy within the next few days. He specially desired to direct the attention of the Members to the editorial which Mr. Dalton had written for the work.

When war was first declared, the cry was: "Business as usual." It very soon, however, became evident that if the war was to be won, as they all intended that it should be, and as they all knew that ultimately it would be, it was necessary that they should devote themselves primarily to the one end and aim of winning the war. As a result of that, a good many scientific and technical societies had curtailed their ordinary activities, but no change of that kind was necessary in the case of their Institution, they had only to consider the extremely important part which petroleum was playing in the conduct of the war, to realise that there was no more effective way in which the Members could serve their country than by improving their knowledge of the industry in which they were engaged, and doing everything they could for its successful promotion and conduct.

At all times since the establishment of the Institution the greatest sympathy and encouragement had been received from

the Press, the technical Press and in particular the oil Press, and on behalf of the Council he was glad to take the present opportunity of expressing their appreciation of the value of the services thus rendered to the Institution, and their hope that such valuable support would be continued.

Before referring more particularly to the paper which was about to be read, he wished to mention that on the previous day the Institution suffered a sad loss in the death of Sir Thomas Bowring, one of the founder Members. Sir Thomas, as most of the Members knew, had taken from the commencement a very active interest in the work of the Institution, and it was only quite recently that he made a generous gift of books of reference to the library.

The Institution owed the paper which was about to be read, primarily to the solicitude which Lord Cowdray, one of the Vice-Presidents, had shown for its welfare. He did not think he was betraying any secret in saying that Lord Cowdray himself would have given a paper on the subject of the Mexican petroleum industry if he had not, with characteristic modesty, disclaimed the possession of adequate knowledge of detail. All the Members knew that Mr. Stewart, who was to read the paper, was exceptionally well qualified for the task. He was a geologist who had for many years devoted special study to the subject of the geology of petroleum in connection with the development of the petroleum industry in Mexico. The author would, he was quite sure, worthily indicate the vast importance of the industry which had been created—an industry which probably would not have been in existence to-day, certainly not in its present magnitude, if it had not been for the remarkable organising ability, perseverance and firm faith which Lord Cowdray, as a pioneer in the industry, had always exhibited. It was interesting to note that the author's father, Colonel C. E. Stewart, who occupied an important diplomatic position, was himself interested in the subject of petroleum, and, from many conversations with him, he (the President) formed the opinion that he was a high authority on the subject of petroleum in Russia. Without further comment, he would call upon Mr. Stewart to read his paper.

The following paper, illustrated by a full series of lantern slides, was then read.

The Petroleum Industry of Mexico.

By P. Charteris A. Stewart, A.R.S.M., A.R.C.Sc., *Member*.

Topography and Climatic Conditions.—Before entering on that portion of our subject which more directly touches the technology of petroleum in Mexico, a word regarding the very varied topography and climatic conditions of the country will probably not be amiss for the better understanding of our subject.

The Southern portion of the State of Texas (U.S.A.) and Northern Mexico is little better than an arid desert, and is only at a comparatively small elevation above the sea.

As one goes southward, the country rises, until at Mexico City, we find ourselves at an elevation of 7500 feet above sea level, on what is generally termed the "Mesa Central" or "Central Plateau."

It is scarcely a "Mesa" or "Plateau" in the geographical sense, as, although the general elevation is high, it is traversed by lofty and rugged ranges. Fringing the "Mesa Central" on either side, are the Sierra Madre Oriental and the Sierra Madre Occidental, which descend precipitously to the coastal plains; these latter varying from a few miles up to 40 or 50 miles in width, and it is on the eastern Coastal Plain that, up to the present, all the commercial oil has been developed. Again, tracing this coastal belt from North to South, the arid character changes to that of the densest kind of tropical growth, with a rainfall of some 75–100 inches per annum.

Before going to Mexico some 14 years ago, I asked a friend for a description of the country, to which he replied, "it consists mostly of cactus, sand and sky."

Now this admirably describes probably two-thirds to three-quarters of the country, but entirely fails to do so with the as yet developed oil regions, where the cactus is almost unknown, while the sand is replaced by one to two feet of mud for nine months of the year, and for weeks at a time, when camped in the thick forest, one scarcely sees the sky.

The rainy season begins early in June with great vehemence, and gradually slacks off until the "Northers" begin in October, these latter being usually accompanied by fine rain and often high winds. They last for three days, and occur almost weekly until the month of March, interrupting the shipping at the smaller ports where there is no protection, and this constant lee shore is a peril to navigation.

Although the thermometer seldom falls below 48° or 54° F., the cold to the human body appears very intense and most penetrating, so that I have seen natives of Minnesota in the Lake District of the U.S.A. (where the temperature often falls to 40° F. below zero), perished with cold, and complaining bitterly during one of these "Northers." This is due to the great humidity of the atmosphere; if the air is heated with a brazier, this effect diminishes very rapidly. The temperature never rises very high during the hot season, and a shade temperature of 104°–107° F. is exceptional, but at the Southern end of the belt in Chiapas and Tabasco, owing to the humidity, it is, for a few days in the year, rather oppressive.

During the first outburst of the rains, the lightning storms are very frequent, and are especially destructive in the oil business, although it is no worse in Mexico than in Texas and Louisiana; moreover, Marconi communication is badly interrupted by them, as the following instance will show:—

During the winter months, the Marconi operators on steamers in Mexican waters can communicate with Cape Cod Station, outside New York, some 2100 miles away (air-line), while, in the lightning season, it is difficult to communicate with Havana, which is only some 950 miles away (air-line), except at about 3 o'clock in the morning.

History. Report says that the Totonacs, one of the tribes of the Aztec family, found, on wandering along the shore of the Gulf Coast, a thick asphaltic oil, which at the time of the Spanish Conquest, was a common article of commerce as far inland as Mexico City, and was dealt in under the name of "Chapopote," said to be derived from the words, "Tzuac," meaning paste, and "Popochile," meaning perfume; it is mentioned by Brother Bernardino de Sahagun, who wrote of it soon after the Spanish invasion.

Report also says that a mention of a spring of oil near Soto de la Marina, was made in a grant of land by the King of Spain on the San Jose de las Rusias Estate in Tamaulipas, and in 1864, Ildefonso Lopez was given a concession to exploit this spring; a similar concession was granted to Parrales in 1865 to work the deposits at Vejarano, also in the State of Tamaulipas.

It is not known whether these also included the subsoil, but as they were subsequent to the "Drake" discovery in Pennsylvania, it is quite possible that these enterprising Mexicans had the subsoil included.

In 1868, Dr. Autrey, of "Angostura Bitters" and "Autrey's Pills and Plasters" fame, discovered the Cuguas (Furbero) deposits,

and a well was drilled to 125 feet without result, but an adit into the side of the hill gave 45 barrels a day, from which source a total quantity of some 200 cans was refined; this was done under the auspices of the Compania Explotadora del Golfo Mexicana, which had but a brief career.

In 1872, J. C. Spear described the petroleum deposits of the Isthmus of Tehuantepec, and in 1873, Señor Prieto those along the Tamesi River in Tamaulipas.

In 1878–9, the Secretary of Hacienda published a report on seepages by J. W. Foster.

In 1879 or 1880, Dr. Autrey "denounced" the property he had previously discovered, for himself, and refined some 4,000 gallons of kerosene.

Between 1880 and 1883, wells were drilled to the north of the Tuxpam River at Chapapote and Cerro Viejo by the owners of the "Boston Post," and one flowing well was brought in at the latter place.

In 1884, petroleum became the property of the owner of the surface.

In 1901, the Mexican Petroleum Company started drilling at Ebano, and brought in a small well at 425 feet in May of the same year.

In 1904, they removed the scene of their operations a few miles to the south of Ebano, to Cerro de la Pez, and brought in their No. 1 well there in April, 1904, which flowed for at least nine years, during which time it gave a production of approximately 3½ million barrels.

In the same year, the Oil Fields of Mexico Company brought in their first well at Cuguas (Furbero) at 1269 feet.

In November, 1904, the Pearson Interests brought in their first well at San Cristobal on the Isthmus of Tehuantepec.

In April, 1908, the same interests brought in the discovery well, San Diego No. 2, and in July of the same year San Diego No. 3 (Dos Bocas) was drilled in, and was probably the largest oil well the world has ever seen, but it was unfortunately uncontrollable, and drained the field. The gas and oil pressure was so enormous that the heavy casing was hurled bodily into the air, and the original 8-inch hole has at the present day developed into a huge crater, from which the daily volume of 15,000,000 barrels of salt water is flowing at the present day.

On February 1st, 1910, the Pearson Interests brought in Tanguijo No. 1 at 115 feet, which gave a high grade oil of 26° Baumé gravity.

In the same month, some 40 miles to the south-west, Potrero del Llano No. 1 was brought in at 1933 feet, and later on in December, Potrero del Llano No. 4 was brought in at the rate of 120,000 barrels daily.

The year 1910 was also an eventful one for the Huasteca Petroleum Company (subsidiary of the Mexican Petroleum Company), as they brought in, in quick succession, Juan Casiano No. 2 in January, Juan Casiano No. 1 in March, Juan Casiano No. 6 in July and Juan Casiano No. 7 in September, this latter well, up to June, 1915, having produced nearly 38,000,000 barrels.

The East Coast Oil Company brought in the Panuco Field in 1910 with a small 20-barrel producer at 1760 feet.

In 1911, the East Coast Oil Company (the pioneers of the Topila Field) brought in Topila No. 2 as a 5,000-barrel well, but unfortunately 95 per cent. of this production was water.

In the same year the Aguila Company (Pearson Interests) brought in Ixhuatlan No. 1 on the Isthmus of Tehuantepec.

In June, 1913, the Penn Mex Fuel Company (subsidiary of the South Penn Oil Company) brought in their Alamo Field, just south of the Tuxpam River.

In January, 1914, the Corona Company (Royal Dutch, Shell Interests) brought in their 100,000-barrel gusher in Panuco Field.

Geology. The Tamasopo limestone in its widest sense, which forms the Sierra Madre Oriental, is a limestone of Cretaceous age characterised by *Rudistes* (a form of *Hippurites*), and at the place from which it takes its name, the portion exposed is, by Böse, said to be of Cenomanian, i.e. upper middle Cretaceous of the Mexican classification, although in its total thickness it embraces the Lower Cretaceous, and in the part of the Sierra Madre Oriental to the west of the oil region, it attains its maximum thickness of over 20,000 feet. Stratigraphically, the Comanche corresponds to at least the lower part of this thickness; the Tamasopo tends to thin to a fifth of this thickness, when traced either north or south. In its upper portion, owing to chemical change and solution channels, it is the reservoir rock of the most prolific wells.

Overlying this limestone comes 600 feet (more or less) of alternating, thin bedded, argillaceous limestones and shales, known as the San Felipe or Valles beds; these may lie unconformably upon the Tamasopo, as they appear to be absent in some of the wells; it is an oil-bearing formation, but probably to a less extent than that of the Tamasopo.

The age of these San Felipe beds is undetermined, as, up to the present, no fossils have been found.

Above these beds come two to four thousand feet of massive, grey-blue marls and shales, known as the "Mendez" or "Los Esteros" group. These beds contain very occasional thin partings of limestone. This group is, by some, mentioned as equivalent to the Laramie, but, if that is now definitely Cretaceous, it will have to be considered as belonging to the Eocene, since the occasional fossils found in these marls are determined as Lower Eocene. These marls form an ideal cover for the oil-bearing beds. They are in many places traversed by dykes and necks, which have allowed the oil to traverse them in the space between the dyke and the marls, causing both small and large seepages of asphalt and thick oil.

Above the Los Esteros come impure fossiliferous limestones and shales, varying very considerably in thickness (600 feet to 2000 feet), and are often locally known as the "Comales" and "Temapache" beds. These, at times, contain some oil, which is of a superior quality, and is probably of a secondary nature, and may have come up from the lower or main reservoir.

We also find numerous and extensive remnants in the forms of isolated "Mesas" of basaltic lava flows in late Tertiary and Quaternary times. The assumption is, that they came from volcanoes situated near the eastern edge of the Sierra Madre Oriental, or they may have emanated from necks, the roots of which are still found on the coastal plain, filling up pre-existing valleys and raising large areas of country to a uniform level.

To the south of Furbero, there are recent deposits of blown volcanic glass, which, owing to their acid character, probably came from other volcanoes than those which furnished the basic basaltic lavas.

The main folding of the region was long previous to these intrusive dykes and necks, but the local structure was at first considered to be due to them, i.e. that in forcing their way through the limestone, they had turned up the edges of the beds through which they had passed, causing the oil to segregate towards those points, thus creating favourable structure. This, according to the more recent studies, is apparently not borne out, as the necks and dykes are not found, on detailed examination, to occupy the apices of the anticlines and domes; sometimes they have been known to occur down the pitch or down side, with the beds dipping slightly towards them. There would be nothing peculiar about this, as on cooling highly basic rocks from the liquid state to the freezing point of water, they are known to contract about $6\frac{1}{2}\%$, and therefore might tend to draw the edges downwards. This tends to prove that even

the smaller structures of the country, were formed previous to these intrusions.

It is noteworthy, that we do not get the large seepages along the outcrop of the oil bearing rock (Tamasopo Limestone) except at one or two isolated points, and at these, there are abundant "keeled Ammonites," which indicate a Jurassic rather than a Cretaceous facies, but these seepages on the outcrop only became known after the oilfields had been developed; bitumen more often occurs at the outcrop as tiny specks of hard asphalt in the vesicles of the limestone, but out on the Coastal Plain along the margins of the dykes and necks, where there has been a passage for the oil to rise, the seepages are abundant and large.

There is one case where an intrusive sill has so metamorphosed and cracked the marls as to cause them to form a very fair reservoir rock.

Enriquez Ordoñez puts forward the idea, which is a little hard to imagine, that there is a volcanically corroded level or sill in the marls, at an average depth of 2500 feet to 2700 feet, which forms the reservoir rock.

In Southern Veracruz, the oil is found in a true sandstone and in a limestone intercalated in the Miocene, while in Tabasco and Chiapas, it is found in rocks probably still younger.

Valuable pointers to the geology are at times to be found from the vegetation, such as the evergreen oak, which is the only tree which will grow on the basaltic "Mesas"; it is also found to be characteristic of the Quaternary sands and gravels, and in addition, in Southern Veracruz, of the red clays.

The tree fern is characteristic of the volcanic ash in Northern Veracruz and the Quaternary sands in Southern Veracruz.

There is a species of palm which bears clusters of nuts covered with spines, which flourishes very well on the Los Esteros and Mendez marls; in this case, it can scarcely be taken as characteristic of them, as it also flourishes in many of the other clayey beds, but a wide expanse of these palms would cause one to be suspicious of the presence of this formation.

Producing Fields. The fields discovered in Northern Veracruz, are Potrero-Alazan, Tierra Amarilla, San Marcos, Valles, Los Naranjos, Tepetate, and Furbero, in which the Mexican Eagle Oil Company hold the sole or controlling interests, while the Ebano, Chijol, Juan Casiano, Cerro Azul and Juan Felipe fields are controlled by the Mexican Petroleum or Doheny Group.

The Panuco, Topila and Chila-Salinas fields are divided into comparatively small holdings amongst 45 companies; the Alamo

field is controlled by the Penn Mexican Fuel Company, while in Southern Veracruz, the Mexican Eagle Oil Company possesses the fields of San Cristobal, Soledad, Ixhuatlan and Tecuanapa; the Sarlat field not yet being exploited commercially.

The Mexican Eagle Oil Company own land in 40 localities, where

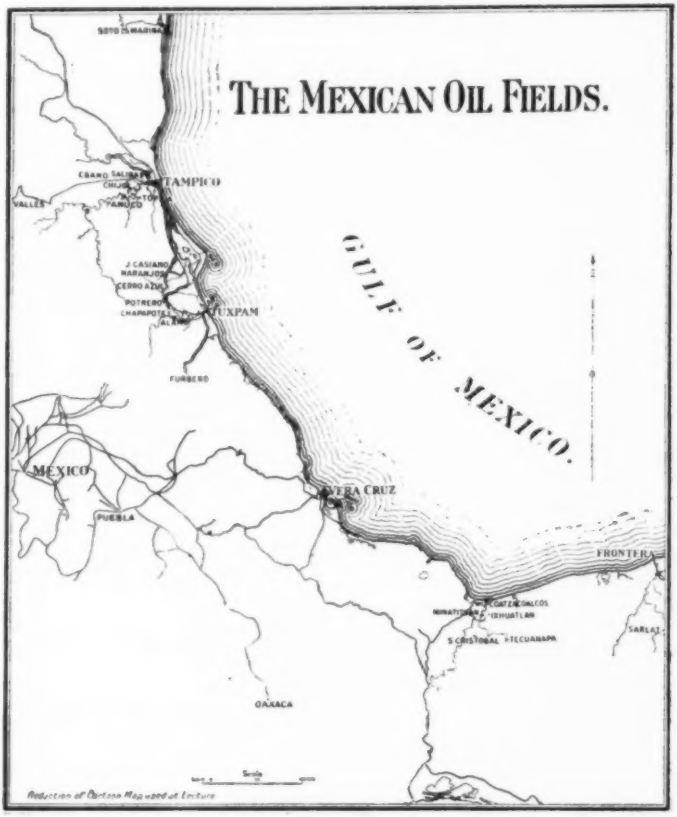


FIG. 1.

there are good surface indications, and drilling has taken place on 13 of these. Oil from seven of them is being marketed, and on five others oil has been found, but not yet in sufficient quantity to warrant the construction of pipelines.

The Mexican Petroleum Company own land in 30 places where

there are surface indications, and oil has been developed on at least five of them.

MECHANICAL. *Sea Lines.*—Owing to the unfavourable nature and the comparatively shallow water close in to the coast, the Mexican Eagle Oil Company originated the idea of laying submarine pipelines to points where the largest tankers could be conveniently moored for loading purposes at any state of the tide and weather.

They have three deep-sea loading berths at Tuxpam Bar, with duplicate pipelines to each berth; the Penn Mexican Fuel Company also have two loading berths equipped in the same manner with pipelines in duplicate.

The first two lines were laid by the Mexican Eagle Oil Company

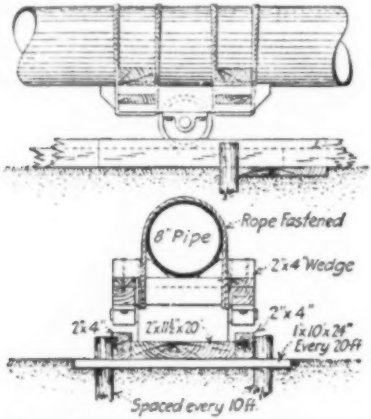


FIG. 2.—Details of Track and Trolleys for launching submarine Pipeline.

for the loading of the Oil Fields of Mexico Company's oil in March, 1910; these were six inches in diameter, and respectively 3608 feet and 5150 feet long below high-water mark.

After being hauled through the breakers, these lines were continued into deep water by laying from barges, which was slow, costly and unsatisfactory work, as on reaching deep water, the pipe developed bends in laying.

In view of the experience obtained with the first two six-inch sea lines, the succeeding eight-inch lines, each 5150 feet long, laid in 1911, were screwed up completely on shore on a carefully-prepared wooden track twelve inches wide, at right-angles to the shore, and directly in line with their permanent locations. The pipe

was mounted on small wooden trolleys, each running on a single roller; the trolleys were lashed to the pipe at alternate joints. The trolleys were removed during launching, by cutting the lashings when they reached the end of the runway, allowing the trolleys to fall into a pit, from which they were removed as the hauling out progressed.

The pipe used for the sea lines was to the following specification:—

Nominal External Diameter	$8\frac{5}{8}$ inches.
Actual „ „	$8\frac{5}{8}$ „
Nominal Internal „	8 „
Actual „ „	$7\frac{7}{8}$ „
Thickness	$\frac{3}{8}$ „
Actual Weight	32·26 lbs. per foot.
Threads	8 per inch.
Taper	$\frac{3}{4}$ to 1 inch.
Angle of thread	60 degrees.
Length of threading	3 inches.
External diameter of couplings ...	$9\frac{21}{32}$ „
Length of recess in couplings... ...	$\frac{3}{8}$ inch.
„ „ couplings (extra long) ...	$7\frac{1}{8}$ inches.
Weight of coupling	30 lbs.

The total weight of one line is 83 short tons (2,000 lbs.)

130 trolleys were used, each taking a weight of 1,277 lbs. or two lengths of pipe. After screwing together, the end of the pipeline was closed by a bull plug, and the whole line coated with Texaco dip applied hot, and spirally wrapped, like puttees, with burlap in strips 20 inches wide, after which another coat of Texaco dip was applied, hot as before.

Uprights with vertical rollers were placed as guides at the water's edge on either side of the runway. An inch and a quarter steel cable 1750 feet long was made fast to the end of the pipeline, and taken out to a 3,000 ton steamer ("San Cristobal") which was used as a tow-boat. In one instance this cable was taken out overnight, and before hauling out commenced, got carried somewhere to the south, and sanded over, so that the first pull was not in the true direction, and the necessity of the guide posts was demonstrated; as a rule, however, after making the initial pull by means of her windlass on anchors previously laid ahead, the steamer had no difficulty in keeping on her course, and towing out the line, at the rate of three to four miles per hour, to within a few feet of the buoyed position, the steamer towing the pipeline being attended by a tug to keep her bows in the correct course, and correct any

tendency to drift with the current, the slow speed of the towing not being sufficient to give the steamer steerage-way.

The lines terminate in 43 feet of water, which is below wave-action, and at the point where the iron pipe ends, 120 feet of armoured flexible hose was attached by divers. The free end of the hose is closed by a blank flange, and allowed to lie on the sea-bottom when not in use, its position being marked by a small buoy attached to the hose by a chain sufficiently strong to lift it.

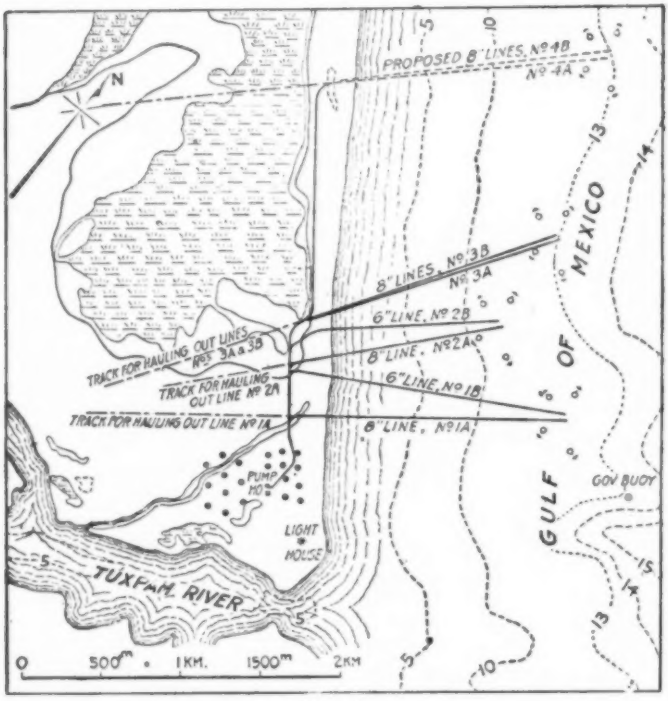


FIG. 8.

The rise and fall of tide is approximately two feet, so that the depth of water, 43 feet, is sufficient for the largest tank steamers to load at any time; tankers of 15,000 tons dead weight, drawing 28 feet, are regularly loaded.

Vessels loading come into position, and moor to the permanent mooring buoys, and are assisted when required by a tug of 1000 hp,

permanently stationed at Tuxpam. After mooring, the tank steamer picks up the marking buoy with the most conveniently situated of her own derricks, and raises the flexible hose alongside the vessel's rail: the hose is attached to the vessel's own loading connections, usually amidships, the weight of the hose remaining on the vessel's derricks.

The necessary control valves for the various lines are on shore, and are so arranged that any loading pump can be used on any line, or two pumps can be used to load one vessel.

The loading station comprises three pump units, each of a capacity of 1500 barrels per hour, or a total loading capacity of 4500 barrels per hour, the pumps being suitably designed for handling heavy crude oils. They are triple expansion, duplex, condensing, and can work up to a pump pressure of 450 lbs. per square inch.

Steam is supplied by the water-tube boilers, and the station is run continuously, allowing loading to proceed at all times.

With the code of signals in force between the pumping station and the vessel, it is possible to load the largest steamers in almost any weather, only fierce northers (75 kilometers per hour) occasionally interfering with loading operations.

As a rule, it takes about 24 hours to load one of the large 15,000-ton tankers of the Mexican Eagle Oil Transport Company, which is equivalent to a loading rate of about 4375 barrels per hour.

Drilling Equipment. Both the rotary and cable systems are in common use. The rotary is particularly efficient in the soft beds, while the cable tools are best for the hard beds, which lie both above and below the great marl series.

A combination system is therefore the most efficient, when installed from the beginning, but when the combination is only made after the well has been started, most expensive and annoying delays occur.

The cable tools require more strings of casing, and cost more for this item than the rotary, but the labour cost is so much less than on the rotary, that the total cost per foot is not very different for the two systems.

Galician pole-tools have been efficiently used by at least one Company, but they are not in general use.

With the cable tools, it is usual to start with 13 inch casing, then diminishing respectively to 10 inch, 8 inch and 6 inch; the

present practice is to cement the last string very carefully into the limestone or other rock, which is expected to be the one overlying the oil, in order that, if a large well be encountered, it may not blow behind the casing.

The Mexican Government require that a gate-valve shall be put on the casing when a depth of 1800 feet is reached (i.e. when approaching the oil-horizon), and drilling continued through this. The oil-horizon generally lies in the approximate neighbourhood of 2000 feet.

With the rotary system, only two or three strings of casing are required, and the drilling is often rapid when passing through the marls.

It has been said that up to four years ago, the costs were $9 to $12 (i.e. 1*l.* 16*s.* 0*d.* to 2*l.* 8*s.* 0*d.*) per foot, but that these costs would be very much reduced, say to $6 (i.e. 1*l.* 4*s.* 0*d.*) per foot. I doubt, however, whether the costs, on an average, have been brought down to as low as this.

I have heard of one well being completed, including casing, for a price as low as $8 per foot (1*l.* 12*s.* 0*d.*), but this is quite exceptional, and I should doubt if there was any profit on this, when taken over a number of wells.

Storage. In Northern Veracruz, up to the beginning of the year 1915, the tankage capacity was approximately as follows:—

Steel Tankage	...	16,500,000 barrels.
Earthen Tankage	...	11,000,000 ,,
Concrete Tankage	...	1,250,000 ,,

From a balance sheet published in 1911, of one of the large Companies, possessing about 4½ million barrels in steel storage, and 2 millions in concrete storage (inclusive of reinforced concrete tanks), the cost of constructing tankage would work out at about 20 c. (i.e. 10*d.*) per barrel for steel storage, and about 4½ c. (i.e. 2¼*d.*) for concrete storage.

Pipelines. There were at the beginning of the year about 430 kilos. (270 miles) of 8 inch, and about 130 kilos. (80 miles) of 6 inch pipelines; other lines accounting for about another 80 kilos. (50 miles), or a total of 640 kilos. (400 miles).

These are reputed to have cost $10,145,520, including material, right of way and pump stations, or about $23,760 a mile or $14,850 a kilometer (2,970*l.*).

The details of the various lines are approximately as follows:—

Mexican Eagle Oil Company, Northern Veracruz.

	Diameter inches.	No. of Tracks.	Kilos.	Miles.	Miles.	Miles.
Potrero-Tampico ...	6 & 8	1 & 2	158·5	99·06		
Potrero-Tuxpam ...	8	1	52·2	32·62		
Tanguijo-Tancochin (abandoned) ...	6	1	28·0			
Los Naranjos—San Diego	8	1	22·2	13·88		
Tuxpam Sea Lines...	6 & 8	3 prs.	4·7	2·99		
					148·55	

Mexican Eagle Oil Company, Southern Veracruz.

San Cristobal-Minatitlan (abandoned)	6	1	23·3			
Minatitlan - Coatzacoalcos (abandd.)	8	1	22·5			
Ixhuatlan-Nanchital	4	1	11·1	6·93		
Tecuanapa-Ribera...	2	1	22·0	13·75		
					20·68	
						169·23

Oil Fields of Mexico Company.

Furbero-Tuxpam ...	6	1	88·0	55·00		55·00

Huasteca Petroleum Company.

Juan Casiano-Tampico	8	3	104·0	65·00		
Cerro Azul - Juan Casiano	8	2	35·2	22 00		
Tres Hermanos-Juan Casiano	8	1	28·8	18·00		
						105·00

Penn Mexican Fuel Company.

Alamo-Tuxpam ...	8	1	44·8	28·00		28·00

East Coast Oil Company.

Ponce-Panuco Field	8	1	15·0	9·37		
Topila Field-Loading Station	8	1	4·0	2·50		
						11·87

National Petroleum Corporation.

Panuco Field — to River	8	1	1·6	1·00		1·00

Various other Companies.

Short lines... ...			49·1	30·70		30·70
					Total ...	400·80

The output from the wells has been entirely dependent on the comparatively limited pipeline facilities, but this limitation in turn has resulted from the lack of road and river transport for building lines.

Pump Stations. *Mexican Eagle Oil Company.*—In its pump station at Potrero-del-Llano (this is the initial station for handling oil through two separate pipelines), the Company probably possesses the largest single oil-pumping plant in Mexico.

The pumping capacity of the pumps installed, including a spare pump, is 82,000 barrels per day of 24 hours, there being two compound pumps each of a capacity of 35,000 barrels per day and one of 12,000 barrels capacity.

Four Babcock and Wilcox Water-Tube Boilers are used to furnish steam, their evaporative capacity being over 50,000 lbs. of steam per hour. Superheaters are fitted to all boilers giving 200° F. superheat to steam generated at 160 lbs. per square inch.

Compound pumping engines are generally adopted, except in places where no fresh water is available, when triple expansion condensing engines are used.

For simplicity of operation, and in order to avoid complications, compound pumping engines are preferable, especially where labour is none too good.

Although the Company's first 8-inch oil line had the pumping stations equipped with large-capacity pumps (35,000 barrels per 24 hours), oil lines constructed later have two pumping engines, both of which operate at the same time, each engine being of 15,000 barrels per 24 hours capacity, or a total of 30,000 barrels per day for the line. Oil fuel is burned on all the 12 pump stations except the initial station at Potrero, where gas from some of the large wells is used.

Huasteca Petroleum Company. This Company possesses six thoroughly up-to-date stations on its main trunk line from Juan Casiano to Tampico, spaced 14 miles apart, and their typical equipment may be expressed as follows:—

1 Wilson Snyder Pump—Corliss flywheel type (12–1400 lbs. per standbye).

1 Wilson Snyder straight line compound Pump.

4 Babcock & Wilcox water-tube boilers—200 hp. each.

The boilers usually burn gas supplied from their Juan Casiano field, but oil-burning apparatus is also installed in case of breakdown, and the change from one to another can be made in a few minutes.

Penn Mex. Fuel Co. This Company possesses two pump stations

and one loading station at Tuxpam (i.e. on their pipeline from Alamo to Tuxpam). The equipment is as follows:—

2 National Transit Co.'s Pumps, triple expansion (23,000 barrels capacity).

4 Oil City Boilers—150 hp. each.

Railways. The lack of roads, the exceedingly wet climate and consequent softness of ground, together with, in a large measure, the lack of hard stone for building roads, and the consequent absence of native vehicular traffic, forced all the larger oil companies to construct some form of railroad for the transportation of their oilfield material from the coast, river or lagoon to the various Camps, and experience has shown that it well repays the original outlay.

Mule haulage is often used where the material has to be rushed in, and before the grades have been cut down sufficiently for steam or gasoline motor haulage; the mules, however, by stepping always in the same places, tend to spoil the track.

A mono-rail system was experimented with, but for the same reason, was abandoned.

There were at the beginning of the year, some 33 miles of 56-inch gauge, some 58 miles of 36-inch, and some 105 miles of 24-inch gauge railways; the following table gives these railways in detail:—

	Gauge. Inches.	Kilos.	Miles.	Miles.	Miles.
Mexican Eagle Oil Co., Northern Veracruz.					
La Peña–Potrero	24	41·00	25·62		
Cuecillos–Los Naranjos ...	24	15·45	9·65		
			——	35·27	
Mexican Eagle Oil Co., Southern Veracruz.					
San Cristobal Landing–Field	24	4·80	3·00		
Soledad Landing–Field ...	24	3·20	2·00		
Nanchital–Ixhuatlan (disused)	24	11·10	——	5·00	
				——	40·27
Oil Fields of Mexico Co.					
Furbero–Cobos	24	81·00	50·60		50·60
Huasteca Petroleum Co.					
San Geronimo–Cerro Azul ...	36	56·00	35·00		
Cerro Azul–Chapopote (survey)	36	30·00	18·75		
„ „ –Piedra Labrada ...	36	7·00	4·37		
			——		58·12
Carried forward					148·99

	Gauge. Inches.	Kilos.	Miles.	Miles.	Miles.
Brought forward					148·99
Penn Mex. Fuel Co.					
Zapatal–Alamo...	24	22·40	14·00		14·00
Mexican Petroleum Co.					
Ebano Camp–National Railways	56½	8·00	5·00		5·00
Tampico-Panuco Oilfields, Ltd.					
Tampico–Panuco (grading completed May, 1915)	56½	45·00	28·12		
Panuco–El Higo (not yet completed)	56½	59·00	36·87		
TOTAL ...					167·99

From a recent annual report of one of the large companies the cost of the 56½-inch gauge railway works out at $44,000 gold (8,000*l.*) a mile, or say $25,000 gold (5,000*l.*) a kilometer, but this price is rather abnormal as it includes a very large amount of siding accommodation, and also three locomotives and eighty tank cars, as well as the cost of joining up with the system of the National Railways.

The value set against the construction of a 36-inch gauge railway, according to a Balance Sheet of one of the principal Companies, is $4,285 gold (857*l.*) a mile, or say $2,678 gold (536*l.*) a kilometer.

RIVER TRANSPORTATION. The Panuco crude was found to be so difficult for pipeline transportation, that, up to the present, no Company has built a line from that field into Tampico.

One short line of 15 kilometers from the field to a point of river loading has not been a great success, as a pressure of at least 800 lbs. per square inch has had to be used to force oil heated to a temperature of 150° F. through this.

Consequently, a fleet of river boats and barges is employed for transporting this oil to Tampico, a distance of 87 kilometers (54 miles).

The fleet at the beginning of the year, was as follows:—

Tow boats, all classes ...	15 (6 tugs, others are stern-wheel tow-boats)
Aggregated Horse Power ...	6125
Number of Barges	56
Aggregated capacity of barges	266,000 barrels.

With this fleet it is proposed to move 75,000 barrels daily from Panuco to Tampico; contract price for barging is at present 6*c*. (U.S.Cy.), or 3*d*. per barrel.

Various people have said that it could be done for less, but owing to the contractors not being in the largest way of business, the prices have not been brought down to less than 5*c*.

Ocean Transport. The clearances from Tampico and Tuxpam for 1914 were:

11,748,371	tons from Tampico,
8,927,986	„ „ Tuxpam.
20,676,357	tons Total.

The Mexican Export trade is served by the largest tankers afloat; these being of a capacity of 15,000 tons or 100,000 barrels and belong to the Mexican Eagle Transport Company.

My excuse for not enlarging on this subject is, that a very comprehensive paper was read on "the Evolution of the Oil Tankship," by Mr. Herbert Barringer, Member of this Institution, at the Seventh General Meeting, on May 28th last, to whom I would refer those who are specially interested in this particular subject.

Refineries. The Mexican Eagle Oil Company has two refineries, one is at Minatitlan, with a capacity of at least 15,000 barrels per day, including a wax plant; there is also one at Tampico to be built in two units, the first unit of which is of 12,500-barrel capacity and is now at work. Amongst other items of plant, there are 10 crude stills worked on the continuous system, fitted with pre-heaters, economisers, &c., in order to reduce the heat losses to a minimum.

There are also Steam Stills, Agitators, Canning Factory, Mixing Tanks, &c., altogether making a very up-to-date plant.

The Pierce Oil Corporation have a 10,000-barrel capacity refinery at Tampico with 32 stills and a wax plant; it is capable of casing and shipping 4,500 cases of refined oil per day, and they also have a 3,000-barrel capacity refinery at Veracruz, but this has been shut down for some years.

There is an asphalt plant at Ebano, and the toppings from this plant are worked up by the Pierce Oil Corporation; this plant also purchases crude from the Huasteca Petroleum Company and from the Mexican Fuel Oil Company (subsidiary of the Pierce Oil Corporation.

The Mexican Petroleum Corporation, to whom the Ebano Asphalt Plant belongs, use their own production for feeding this plant.

The Huasteca Petroleum Company has just commenced operating a topping plant at Mata Redonda (Tampico Terminal) of 10,000-barrel capacity of crude, although at the beginning of the year it was not quite finished.

The Standard Oil Company of New Jersey have lately installed a topping plant at Tampico Bar with a capacity of 4,000 barrels of crude per day.

Refining. After considerable experiment it has been demonstrated that Mexican oils are well adapted for continuous distillation, although the first plants in the country were erected for intermittent distillation, but the later refineries are being built on a continuous plan, and the older plants are being converted to it.

High class spirit and kerosene of excellent colour is now being manufactured from these oils, and there is a residue of high calorific value, which is eminently adapted for fuel oil, and is being exported to the U.S.A., Great Britain, and South America.

Considerable trouble was encountered at first in eliminating the sulphur, but this has been largely overcome.

The domestic trade in kerosene before the troubles in Mexico began, was about 2,000 barrels a day, this being about equally divided between the Mexican Eagle Oil Company and the Pierce Oil Corporation.

The Mexican Railways and some of the southern and eastern Railways of the United States use fuel oil exclusively.

The analysis and specification of Mexican fuel oil is approximately as follows:—

Carbon	83·52 %
Hydrogen	11·68 %
Sulphur	3·27 %
Ash	0·16 %
Undetermined (presumably Oxygen and Nitrogen)	1·37 %
	100 %
Sp. Gr. at 60° F.	about 0·950 or 18·2° B.
Flash Point	above 150° F.
Viscosity at 100° F. (Redwood No. 1)	1500 secs.
Calorific value	18,900 B.T.U. per lb.

In the past some prejudice has existed against an oil containing more than 0·75 % of sulphur, although no scientific reason can be given for fixing this or any other arbitrary figure. No objection, however, is made to the presence of sulphur in coal, nor any record of deterioration of boilers on this account. It is significant that

Character of Mexican Oils.

	Mexican Petroleum Company.	Huasteca Petroleum Company.	Penn Mex. Fuel Company.	Panuco Fields.	Topila Fields.
Colour	Dark	—	—	Black	—
Temperature (Fahr.) ..	105°	—	—	—	—
Asphalt (per cent.) ..	45	—	—	—	—
Gasoline (,,) ..	3 to 5	—	—	—	—
Distillates (,,) ..	55 (this is sold to the Waters Pierce Refy.)	—	—	—	—
Gravity (Baumé) ..	10½°–12°	19·3°–19·4	22·15°	11·6°–12·56°	14·5°
Flash Point (Fahr.) ..	—	80°–96	45°	(open) 164·5°–175°	165° (open)
Sulphur (per cent.) ..	—	1·93–2·08	—	4·28–4·81	4·40
Bottom Sludge(percent)	—	2–3	0·60	3·75–4·00	—
Calorific Value .. (B.T.U. per lb.)	—	19,124–19,160	—	17,570–39,362	39,961
Fire Test (Fahr.) ..	—	—	—	200°–249·5°	—
Viscosity at 100° Fahr. (seconds, Redwood)	—	—	390	930	4,000

The Ebano Oil of this Company has an asphalt base, and is specially valuable for the manufacture of high grade asphalt, which is done at Ebano Refinery. Theabove analysis refers to this Ebano oil.

The above analysis refers to the Juan Casiano well. The oil is very successfully used for the manufacture of illuminating gas in Mexico City, and when used for making steam at the gas works in question, an evaporative capacity of 16 lbs. of water to every lb. of oil is the regular result.

The above analysis refers to the good class of oil that has been discovered on their property to the south of the Tuxpam River.

The Mexican Eagle Oil Company.—It will be seen from the above analyses of the Panuco and Topila Oils that they are rather on the heavy side, so that Pearson Interests have devoted themselves to regions further south, where the oil is distinctly better, and can be economically pumped through pipelines. In the State of San Luis Potosi, the company went in purely on geological structure and indications, and discovered a very high-grade oil of 0·783 sp. gr. Further south, in their Potrero Field, they have an oil of an average gravity of 0·926 sp. gr. or 21·3° B., with an average well-temperature from latest reports of 108·3° F.

In the Isthmus of Tehuantepec or Southern Belt, there are oils ranging from 0·881 to 0·792 sp. gr., with viscosity varying from 108 to 30 secs. Redwood. These latter oils contain large quantities of high grade illuminating oil, and some of them are almost free from asphalt, which enables a high class lubricating oil to be manufactured, troublesome to obtain from crude oils high in asphalt. The oil appears to become better and better as we go southward, but this fact is purely accidental, as the oil comes from quite different horizons.

the amount of coal of average quality required to give an equivalent heating value to a pound of oil would contain more sulphur than is contained in one pound of Mexican fuel oil. The extensive experience with oil burning which is now available, shows that boiler corrosion does not take place. The only point that need be mentioned in this connection is that it is advisable, when steel chimneys are used, that the temperature of the flue gases should not fall below 400° F., a contingency which rarely arises in actual practice.

The only drawback attaching to the presence of sulphur in fuel oil is that its heat value is somewhat low, i.e. 4500 B.T.U. per lb., and consequently the total B.T.U. per pound of oil are slightly lower on account of its presence. The fact that the British Admiralty have, after careful investigation, raised the percentage in their specifications from the conventional standard of 0·75 % to 3 % reflects the altered views on this question.

The manufacture of high grade lubricating oils was for a long time a difficult matter, but these are also now being successfully made.

The oil contains both asphalt and wax, and the refineries are now adding wax plants to their outfits, so that advantage may be taken of this product.

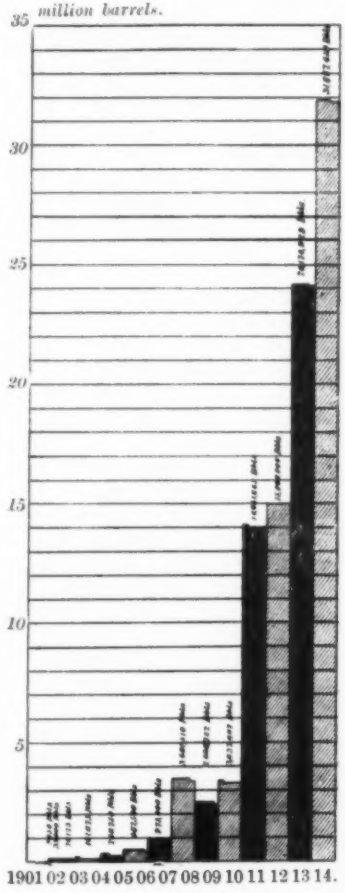
There was a large Continental trade in Mexican asphalt and boiler paints; this asphalt is also successfully used for paving the larger Mexican towns; in the eastern cities of Canada, even as far west as Winnipeg, it is successfully used in a climate which probably puts asphalt to one of its severest tests, as the temperature varies from 40° below zero to 90° Fahr., and here it has withstood the keen competition of the Californian product.

It has also been extensively used in this country under the names of "Mexphalte" and "Fluxphalte" in the capacity of binders in road construction. Their use has been attended with the greatest success.

Statistics. *Drilling Wells.*—Up to the end of 1912, 420 wells have been drilled in Mexico; during 1913, 130 wells were drilled, and in 1914, 87 wells were drilled, making a total up to the beginning of the year of 637 wells.

Present Operations.—From recent reports, the present operations of the various operating companies in Mexico may be briefly summarised by fields as follows:—

Field.	Well Producing.	Abandoned.	Drilling.
Panuco	55	9	28
Topila	17	12	10
Chila, Salinas and Caracol...	10	8	8
Southern Fields (Tampico-Tuxpan region)	11	3	29
Totals	93	32	75



Annual Yields in U.S. Barrels.

1901.....	9,750
1902.....	39,000
1903.....	78,125
1904.....	101,875
1905.....	248,750
1906.....	487,500
1907.....	975,000
1908.....	3,481,410
1909...	2,488,742
1910.....	3,832,807
1911.....	14,051,643
1912.....	15,000,000
1913.....	24,174,929
1914.....	31,867,410

FIG. 4. Production of Petroleum in Mexico.

Steel Tankage.—At the beginning of the year, the principal steel tankage of the various companies was as follows:—

Mexican Eagle Oil Company	3,642,000	barrels.
Huasteca Petroleum Company	6,489,000	,,
Tampico Company	336,500	,,
Freeport Mexican Fuel Company ...	570,000	,,
Mexican Fuel Company	257,500	,,
Mexican Gulf Oil Company	480,000	,,
Standard Oil Company of New Jersey ...	330,000	,,
International Petroleum Company ...	542,000	,,
Magnolia Petroleum Company	110,000	,,
Corona Petroleum Company	680,000	,,
East Coast Oil Company	690,000	,,
Pierce Oil Corporation	495,000	,,
Producers Oil Company	120,000	,,
Chijoles Oil Limited	20,000	,,
National Oil Company	275,000	,,
Mexican Oil Company	6,500	,,
Topila Petroleum Company	37,500	,,
M. C. Anderson	2,000	,,
Tampico Oil Limited	80,000	,,
Mexican Petroleum Company	760,000	,,
Penn Mex. Fuel Company	665,000	,,
Oil Fields of Mexico Company	86,000	,,
Total	16,674,000	barrels.

Taxation.—U.S. Gold Values. This has been very much increased of late years, and at the end of last year, the cost of production being 10 c. per barrel was still further augmented, principally by taxation, to 33 c. per barrel, as the following table will show:—

Bar Dues (Tampico)	$0.0381
Production Tax	0.0457
Royalty 10%	0.0375
River Transportation	0.0600
Production Expenses	0.1000
Terminal Charges...	0.0500
Total	$0.3313

At the Port of Tampico, bar dues are enforced to the extent of 25 c. per ton.

The production tax which was promulgated at 10 c. per ton in 1912, has now jumped up to 30 c., also the taxes issued by the Veracruz State Government have risen from $17,500 to the neighbourhood of $120,000 (exchange taken at 2 Mexican silver to 1 U.S. gold).

In a report for 1911 of one of the large Companies, it was stated that oil could be put on board the steamers or tank cars at Tampico

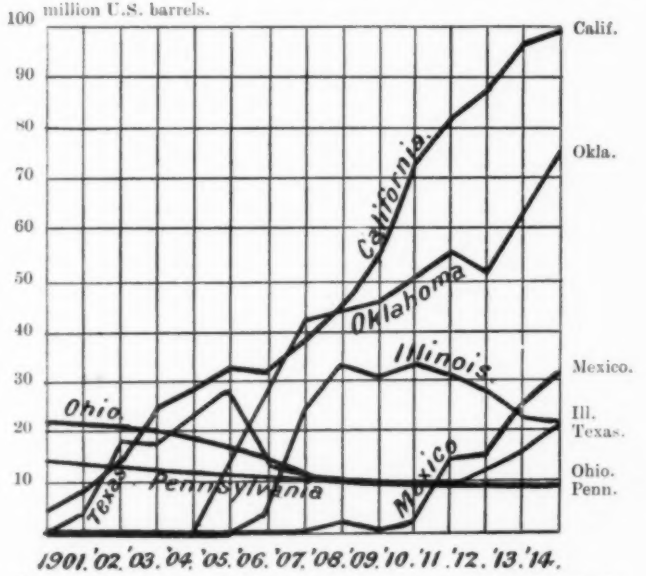


FIG. 5. Mexican petroleum production as compared with that of the principal States of America over the same period.

for 13 c. per barrel, but it will be seen from the above that it would be hard to do the same at the present time.

From the same report it is mentioned, that the Company's contracts averaged 54 c. per barrel.

In Pennsylvania, properties were selling at $900 for each barrel of daily production, when their oil was fetching $1.30 per barrel, while the Mexican properties were worth $300 per barrel of daily production with oil fetching 54 c. per barrel.

Life of Wells.—The life of some of the large Mexican wells has

been long as well as prosperous. The Mexican Petroleum Company's Pez No. 1 flowed for at least 9 years (3.4.04–3.4.13), giving a production of 3,450,000 barrels, and Pez No. 6 gave 1,763,612 barrels over a period of 4 years (2.1.09–2.2.13).

The Huasteca Petroleum Company's Juan Casiano No. 7, which came in September, 1910, has produced in the neighbourhood of 38,000,000 barrels up to June of this year.

The Mexican Eagle Oil Company's Potrero del Llano No. 4, which came in December, 1910, had given up to June, 1915,

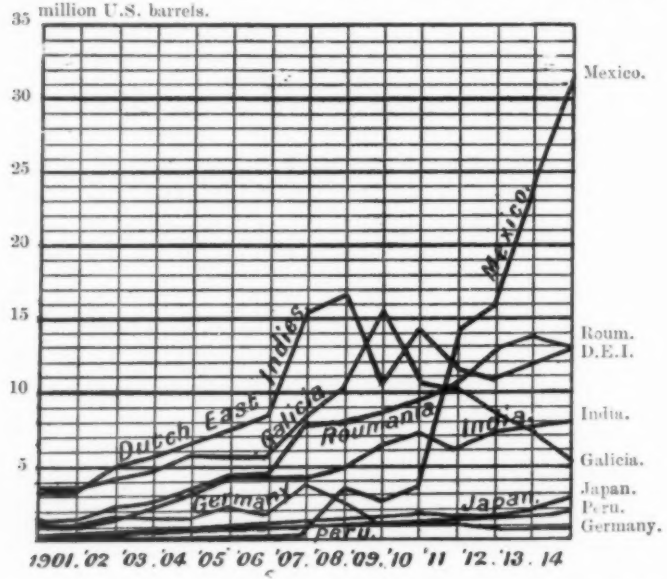


FIG. 6.—The world's production of oil 1901–1914, excluding that of the United States of America and Russia.

approximately 45,000,000 barrels, but this well was shut in entirely for two months, and during the greater part of its life it has only been allowed to produce up to the capacity of the pipe line, i.e. 37,000 barrels per day; its open-valve capacity, however, being considerably over 100,000 barrels per day.

Mention has been made earlier in the paper of the Mexican Eagle Oil Company's "Dos Bocas" well; this has been probably the most spectacular well in the world; it burnt for forty days with a flame mounting up to about 1,800 feet in height, and newspapers could

be read about seven miles away by its light. After some months, the enormous flow of this well turned to salt water. All estimates of the quantity of oil made at the time, would, in view of the large production which has since been attained through wells in which the casing has held, point to its having been an almost inconceivable quantity, as the well was flowing wild outside the casing, and latterly formed a crater which became enlarged to many acres in extent, owing to severe caving, and the carrying away of this caving by the salt-water river which proceeds from it. As beforementioned, some tens of millions of barrels of salt water a day is now flowing from it.

The charts of petroleum production, figs. 4–6, may be of interest as showing the rapid progress that Mexico has made in this respect during the last few years.

I have endeavoured within the compass of a short paper to describe the wonderful strides made in the development of Mexico as an oil-producing country from its modest inception in 1901, a development which it is to be hoped—with the restoration of peace and a strong Government—will still further be increased, and that its petroleum wealth may take an even worthier place than heretofore in the world's history of a product that is daily becoming more and more essential in an age of civilization and progress.

I have to express my thanks to Mr. J. S. Smith, Chief of the Engineering Department at Messrs. Pearsons' Parliament Street offices, for his valuable assistance in revising the mechanical section of this paper, and to Mr. W. H. Dalton for help with the subjoined bibliography.

Mr. McConnel Saunders was to have contributed a section regarding the chemistry of Mexican oil, but he writes to say that the time has been too short, and that the Company's work has been too pressing to prepare this.

Some of the other chemists and geologists of the Company have also been making special researches into this subject, and believe that they have discovered a method of diagnosing the previous life-history of many oils.

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DISCUSSION.

The President thought the Members would agree that from the practical point of view the paper was one of the most valuable that had been presented to the Institution. Apart from its geological value, it contained a vast amount of technical information which would be found most useful to the oil engineers in many other countries besides Mexico. It was, in point of fact, a unique record of geological and engineering experience in dealing with an industrial oil problem on a scale of vast magnitude, and he was quite confident that the data which had been given might be profitably studied at leisure by every oil engineer, however highly competent and experienced he might be.

Prof. Cadman, in opening the discussion, said he desired in the first place to express his thanks to the author for the comprehensive nature of his interesting paper. In dealing, in the space of an hour, with such a vast subject, covering practically every phase of the great petroliferous industry of Mexico, the author had undertaken a very difficult task, and he was sure the members present appreciated the way in which he had dealt with it. The author had touched upon some of the interesting geological

problems with which this field bristled, and he hoped the geologists present would enter into the discussion with the vigour characteristic of geologists. The meetings of the Institution had been enlivened from time to time by discussions upon geological questions, and he hoped this particular instance would prove no exception.

He would like to know a little more about the intrusions of basaltic matter which, from the diagrams, seemed to appear in a rather extraordinary manner, rising in the centre of domes. So far as he understood the author's statement, the oil zones always seemed to occur on the top of these deep-seated basaltic masses. Was this really the case? The sketches shown seemed to illustrate that the intrusions were instrumental in producing a structure which all geologists knew to be favourable to the concentration and preservation of petroleum. He desired to ask the author whether any information was available, from the various wells which had been drilled in such localities, to demonstrate to what extent the structure of the oil-bearing porous bands had been influenced by such intrusions.

He next desired to ask the author whether he had any information regarding the characteristics of the porous bands. He understood Mr. Stewart to say it was a limestone, and he would like to know whether, from the drilling material, he had been able to ascertain the characteristics of that limestone: was it detrital?

He had been very much interested in the graphic description given of the laying of the pipe-lines in the Gulf. It was a great engineering feat, and one on which he was sure the engineers present would congratulate those who were responsible for the operation. With reference to one of the concluding remarks of the paper with regard to taxation, it revealed an interesting condition of affairs. It appeared that the taxation amounted to approximately ten shillings a ton. It would seem that either the Mexican Government were to be congratulated upon their anticipated values of Mexcian oil, or the companies operating in Mexico were to be sympathised with in the heavy burden thrust upon their work. Mexico was an area of which he had no personal experience, and he was sorry that he could not add to the discussion, but he desired again to congratulate the author heartily upon the production of such an interesting account, embodying so many phases of the great oil industry of that country.

Mr. F. A. Holiday, having thanked the author for his most interesting and instructive paper, said he desired to ask a few questions on three points to which reference was made. Dealing

first with the geological part of the paper, the Tamasopo limestone was referred to, both in the paper and by many other writers and investigators, as if it were, if not the source, at least the main reservoir of the petroleum which was now found in Mexico. In the only district of that country with which he was acquainted, i.e. the Panuco field, there did not seem to be any evidence that the Tamasopo limestone had been reached. Certainly there was no geological evidence on the surface of the ground. Marls were first of all penetrated and, at a lower depth, limestone layers, which became more important the deeper the bore went, but it seemed to him very doubtful if the real Tamasopo limestone was ever reached. The wells in the Panuco field produced at about 1800 ft. to 2700 ft. Oil was encountered at much smaller depths, but the actual producing wells varied between those depths. But the chief wells were not the deepest in the field ; the most important wells produced at from about 2000 ft. down to 2300 ft. So that it did not appear that by going deeper the output of oil was increased, or that they got further into the reservoir.

The second point to which he wished to refer was the viscosity of the oil, which was a very important point. It was stated in the paper that the Panuco oil was taken down to Tampico in barges because it was too viscous to send through a pipe-line. One point that must be borne in mind was that the Panuco field had been developed since the country had been in a more or less unsettled state, and that the companies had perhaps been afraid to expend the capital necessary to lay a pipe-line ; but he had heard it stated that permission had been granted for a pipe-line to be laid from Panuco down to Tampico. It was mentioned in the paper that in an experiment made with the oil in a pipe-line about 15 kilometres long, a pressure of 800 lbs. had been used, at a temperature of 150° F. That was exceedingly bad ; it would mean a very viscous oil indeed. Some figures that he had seen suggested that the oil was not as viscous as the author stated. He had heard it said that in the particular case to which reference had been made, the oil had been allowed to cool in the pipes, and to form a sort of plug, so that a pressure of 800 lbs. had to be used in order to overcome the stoppage due to the plug. Perhaps the author could state whether the figures he had given were taken some time ago, when the pipe-line was first tried. It seemed as if the oil could be transmitted at a reasonable temperature, perhaps not much above 100° F. in a pipe-line which was warmed at intervals at the pumping stations, particularly if the line were kept clean by washing it out with water, so that plugs were not allowed

to form at times when oil was not being transmitted. He would also point out that the number of wells now in course of drilling in the Panuco field was about 37, instead of 28, as stated in the paper, but owing to the state of the country they were practically all stopped at the present moment.

Dr. J. A. Leo Henderson said he had listened with the greatest interest to the description the author had given of a region unknown to many oil geologists, and which was the Cinderella of the oil-fields of the world. Especially interesting to a geologist was the Cretaceous Tamasopo limestone as a reservoir-rock, to which Professor Cadman had also referred. A number of papers had been published during the last few years upon the Mexican oil-fields, and allusions had been made to the presence of arenaceous or sandy layers in the limestone, which presumably might form the reservoir of the oil. He noticed in the paper that the storage-capacity of the limestone was attributed to solution channels, which would form a very suitable "open" reservoir-rock to explain the enormous gushers which had been brought in. He thought it would be of great interest if the author could insert a note giving the temperature of the oils from, or of the rock in, the various wells. The temperature of the waters, of the oils encountered, and of the rock itself as the depth of the wells progressed would, he thought, attract a good deal of attention in the oil world in the future. Sufficient attention had not been paid to that factor in the past, and it would be of great assistance if the author could give any information on the subject, as bearing upon the Mexican oilfield conditions. He did not quite gather whether the author considered that some of the so-called basaltic necks or domes were not really basaltic but something else, and he would be glad if that point could be cleared up. The downward inclination of the beds at the side of the volcanic necks referred to reminded him very much of a similar phenomenon which occurred in connection with some of the volcanic necks containing diamond-bearing basic igneous rock in South Africa.

Mr. Lewis Hamilton said the only thing that struck him in connection with the porosity of the rocks mentioned in the paper was that in his wandering over the fields of Mexico he could not help noticing the character of the stones on the surface of the ground, mainly bits of basalt. A very great number of those stones were full of cavities, some of which were as large as one's finger. This would indicate that the basaltic formation must also be porous here and there, and possibly to a considerable extent and over wide areas.

Mr. Foster Bain said the point the author had made in his paper with regard to the divergence of opinion from the common notion of the relation of the oil to the volcanic plugs in Mexico was new to him, and he would be glad to know whether it simply meant he had not kept in touch with the literature on the subject during the last few years or whether that divergence of opinion had not been previously expressed. From the geological point of view, it was one of the most interesting and significant points in the paper, and if the subject had not been previously dealt with, he hoped that a detailed geological report on the point would be forthcoming, because it would certainly be received with very great interest.

Mr. Stewart, in reply to Professor Cadman's question, said he was afraid there was not much proof one way or the other of the plugs having promoted the segregation of the oil or not, except that the plugs did occur very frequently in the dome somewhere, but they were not always at the apex. It was therefore impossible to say that the plugs really caused the segregation of the oil towards their positions, but they might have done so. On the other hand, the fact that they were on the side rather pointed to the structure having existed previously to the intrusion of the plug.

Prof. Cadman enquired whether the plugs were found in any case where the structure was not a fold.

Mr. Stewart replied in the affirmative. There were, he said, several cases of plugs occurring far down, practically in synclines, and these showed no seepages. He was rather sceptical as to whether all the supposed basaltic plugs were basaltic. Certainly many of them were, but in others nothing basaltic could be seen about them. They were called basaltic plugs, although no basalt was seen. The plugs where no basalt was found showed signs of hot water, and the beds were merely marls very highly indurated. They might be outliers of some harder stuff, or else they might be normal beds, locally hardened by hot springs. He thought they were very much more likely to be the latter. There was no doubt, however, that oil seemed to occur round several of them just as it did round true basaltic plugs. Mr. Hamilton had referred to basalt being found with cavities in it. Basalt nodules with cannon-ball weathering were certainly found; at times the centres were hollow; very pretty lining crystals of calcite were obtained, and sometimes he had found them filled with oil. He did not think, however, they were right in thinking that the basalt was the reservoir rock. Mr. Foster Bain had referred to

a divergence of opinion. He did not know exactly to what he referred, but he probably meant the sinking down of the beds around the cooling plugs. He rather thought they did sink down, probably owing to contraction; but in their own fields it had been found that the necks were by no means always on the axis, and other people seemed to have had the same experience. Of course one would immediately jump to the conclusion when the neck and the dome were found that the neck was at the apex, but that had not proved to be the case.

With regard to cavities in the limestone, beyond a few pieces blown out occasionally, it was not known what the limestone in the wells was like. There were some very porous portions to be found on the outcrop, but to what the pores were due he did not know. The limestones were supposed to have been denuded before the next series of beds was deposited; therefore there might have been channels cut by water at the time of the denudation before the formation of the overlying beds. Mr. Huntley in a recent paper said that the channels were opened upwards, and that the production came from the limestones and shales of the Valles beds, which lay just above the Tamasopo limestone; he held the oil-reservoirs to be a sort of shrinkage cracks in those beds, and the shallower wells often struck some better shrinkage cracks than the deeper. He quite agreed with Mr. Holiday's statement that the deepest wells were by no means the best.

Dr. Henderson had referred to arenaceous layers in the limestone. There might be arenaceous limestone in the Valles beds which overlie the Tamasopo, but he did not know of any arenaceous beds in the Tamasopo itself. Very likely in the Panuco field the wells did not get down to the Tamasopo. Some people said they did go down to the Tamasopo, and others said they did not, but, in view of what Mr. Huntley had said, probably they did not.

Reference had been made in the course of the discussion to the plugs in the pipe-line. He understood that the pipe-line worked at one time even worse than as described in the paper. The information he gave in the paper was the latest that he could obtain. He believed when the line was tried after it was laid it was a failure. Another engineer was then sent down who improved matters, and the figures he had quoted were those that were obtained under those conditions. Of course it might have been improved since. If it were working at 700 lbs. it would not be so bad, but 800 lbs. was rather a tax on a pipe-line. Of course it might not have been kept warm along the line; he could not say whether this was the case.

Temperatures had been taken in the wells very carefully, and the figures were most instructive, but very little had been done with them hitherto. It was found, however, that in those wells which went down too deep, and where it was unlikely that oil would be obtained, the temperature rose rapidly, and it was therefore a fair presumption that oil would not be obtained by continuing to drill.

Prof. Cadman asked how the temperatures were taken.

Mr. Stewart said he was afraid he could not properly answer that question. Mr. de Golyer, who was in charge of the investigation, had a special instrument for taking the temperatures. He did not know the construction of the instrument, but he knew the results obtained showed that if they were going down too deep, the temperature rose rapidly in some of the wells, and in others it did not.

The taxation to which Professor Cadman had referred was exceedingly heavy, and some of the companies did not quite know where to turn in that respect.

On the motion of **The President,** a very hearty vote of thanks was accorded to Mr. Stewart for his most interesting and valuable paper, and the meeting terminated with the exhibition by **Mr. W. Sutton** of a series of admirably-executed and very interesting panoramic and other photographs of the Panuco field.

Ninth General Meeting.

The Ninth General Meeting of the Institution was held at the house of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, the 16th of November, 1915, Sir Boverton Redwood, Bart., D.Sc., F.R.S.E., President, occupying the Chair. The following Members of Council were present: Dr. George T. Beilby, Professor John Cadman, Mr. E. H. Cunningham Craig, Mr. Arthur W. Eastlake, Sir Thomas H. Holland, Mr. T. C. Palmer, Dr. F. Mollwo Perkin, and Mr. Robert Redwood.

The President, in opening the Meeting, said that since the last meeting the Institution had sustained a severe loss in the death of Professor Vivian B. Lewes, who was a Member of the Council. He had taken a very keen interest in the work of the Institution from the time of its inception, and was a regular attendant at the meetings. Many of the Members would remember the eloquent and inspiriting address which he delivered at the Inaugural Meeting. Probably nowhere was Professor Lewes better known or a greater favourite than in the hall of the Royal Society of Arts, for during the past 25 years he had made no less than sixty appearances on that platform. He had exceptional ability in dealing with scientific subjects in language devoid of any unnecessary technicalities, and he had the gift also of enlivening his remarks with humorous allusions. He was able to invest his remarks with the attributes of spontaneity, whatever might have been the labour which he had devoted to their preparation, for he invariably lectured without a single note, and he was never at a loss for a word. In public and private life alike, he won the affectionate regard and esteem of all who knew him, and he died a martyr to his strong sense of duty and his conscientious consideration for others, because he persisted in striving to fulfil an engagement to deliver a lecture in Wales on matters connected with the war when he was really too ill to undertake the journey. His friends tried to dissuade him from going, but his characteristic reply was: "I have never yet disappointed an audience, and I cannot do so now."

The Institution was honoured that evening by the presence of Dr. Glazebrook, the well-known and talented Director of the National Physical Laboratory, who, amidst the exacting and responsible official duties which he was at present discharging in connection with the war, had found time to attend the meeting, and to deliver an address which would certainly be of great

interest and instructional value. In that connection the Institution was also favoured by the Lords Commissioners of the Admiralty, who had given permission for the publication of the results of the experimental investigation upon which the paper was largely founded.

The following paper, illustrated by lantern slides, was then read :—

The Viscosity of Oils in relation to the Rate of Flow through Pipes.

By R. T. Glazebrook, C.B., D.Sc., F.R.S., Director of the National Physical Laboratory, W. F. Higgins, B.Sc., and J. R. Pannell, A.M.I.M.E.

The tests here described were undertaken at the request of the Admiralty, and the following account of them is given with their Lordships' permission.

Their object was to investigate the laws of flow of the oil in drawn steel pipes of varying sizes, with a view to determining how far the pressure difference required to produce a given flow could be calculated from a knowledge of the dimensions of the pipe and of the viscosity of the oil. With this object in view it was arranged that experiments should be made on the flow of four oils in pipes of three, four and five inches diameter. These are described in Part I of the Report.

It appears from the results of this part of the work that the ordinary laws of viscous flow hold, so long as the velocity of flow is less than the "critical velocity," which is given by the equation $\rho Vd/\eta = 2500$, where V is the velocity of flow in feet per second, d the diameter of the pipe in feet, ρ the density, and η the viscosity coefficient in foot-pound-second units. In this case :—

$$\frac{P}{V} = \frac{2\eta}{9gd^2}$$

P being the pressure difference in pounds per square inch per foot run, and g the acceleration due to gravity in foot-second units.

Part II of the Report deals with the determinations of the densities and viscosities of the oils used at various temperatures, and the measurement of their flash-points. Similar measurements are given on three additional oils. It also includes determinations of the same quantities for mixtures of the various oils, with the results of some observations on the permanence of the mixtures.

Certain anomalies in the behaviour of Mexican oil are also investigated, while the concluding section of this part describes an investigation into the lowest temperature at which one of the oils can be made to flash.

The observations in Part I were carried out in the Engineering Department of the Laboratory, under Dr. Stanton, by Mr. Pannell; while those in Part II were made by Mr. Higgins, an assistant in the Physics Department.

Part I.

The Resistance to Flow.

As regards the determination of the frictional coefficients, the Laboratory was asked to determine the friction in pipes of three, four and five inches diameter at speeds up to 1·5 ft. per second, and above if possible, and at temperatures between 35° and 120° F.

Primâ facie the obvious method of making the tests appeared to be that of forcing the oil through the pipes by the ordinary type of pump used for the purpose in the Service, and to measure the drop of pressure along a measured length by observations of the pressures indicated by Bourdon pressure-gauges screwed into the pipe at each end of the measured length. This was the method previously in use.

On further consideration, however, and from observations of existing plant, this method appeared to be unlikely to give results of a fair order of accuracy, for the following reasons.

(1). Assuming the motion of the oil to be stream-line in character, the pressure-drop per foot run of the pipe would, in the majority of the experiments, be of the order of one-hundredth of a pound per square inch. Unless, therefore, a very considerable length of pipe were used, involving several return bends, the use of Bourdon pressure-gauges was out of the question, since these gauges would not be reliable in measuring a pressure-difference of less than 5 pounds per square inch.

(2). Strong objections also appeared to the use of an ordinary reciprocating force-pump, on account of the fluctuations of pressure produced by the inertia of the large mass of oil in the pipe, and the possibility of damping these out by multiplication of pistons and the use of air-vessels seemed likely to prove very costly and difficult.

As regards (1), the alternative suggested itself of measuring the distance of height of two columns of the oil, one connected to each of the pressure-holes at a given distance along the pipe.

This is the ordinary laboratory method of measuring the hydraulic gradient along a pipe. Some preliminary experiments were tried with this method, but the time lag of the movements of the oil columns was so great that it was impossible to follow the changes of friction in the experimental pipe due to small alterations of temperature. The difficulty will be apparent from the consideration that at the ordinary temperature a change of temperature of the oil by 1° Fahrenheit will change the friction by 5 %.

As regards the method of measuring the frictional resistance, this resolved itself into the adoption of a sensitive gauge for measuring small pressure-differences, which would follow the fluctuation of pressure inside the pipe pretty rapidly. As regards a mechanism for producing the flow, which would not have the drawback of the ordinary direct-acting pump, the alternatives appeared to be (1) a gravity method, by means of which the flow took place from one level to another under gravity, the discharge being returned by pumps, (2) the use of a rotary pump, by means of which a continuous flow could be maintained, the fluctuations of pressure in the main being solely due to fluctuations of speed of the motor, which are under control.

As regards the relative merits of these methods, the gravity method was considerably the more costly of the two, as it would have involved the construction of staging of considerable height, and there was the added disadvantage that, in the case of the more viscous oils, even with a considerable gravity-head, the limiting velocity which could be obtained would be so small as to be of little use for the purpose of the experiments. Thus, taking the use of Mexican oil from which the value of η at 50° F. is 9, and assuming a gravity-head of 50 ft. and a total length of pipe of 100 ft., the formula for the loss of head is

$$H' = \frac{100}{\frac{Wd^2}{\eta V} - 1}$$

where W = weight of oil per cubic foot. Putting $H' = 50$ we have

$$V = \frac{Wd^2}{3\eta} = \frac{59}{9 \times 3 \times 9} = \frac{59}{243} = 0{\cdot}25 \text{ ft. per sec.}$$

For these reasons the use of a rotary pump was decided upon, and a two-stage centrifugal pump was specially designed for the purpose. This has proved successful as regards the quantity passed through the apparatus, and the avoidance of all disturbances in the velocity of flow and the pressure-head in the pipes, but an unforeseen difficulty has been the dissipation of part of the energy used in driving the pump, in heating the oil in its passage through

the pump. As a consequence, when pumping the *thick* oils, the temperature of the oil in the discharge-pipe was appreciably higher than in the suction-pipe.

The pump was provided with a suction-tank containing a nest of circulating coils for heating and cooling the oil, and a discharge-tank mounted on a weighing machine for estimating the amount of discharge. The general arrangement of the apparatus is shown in the figure. It will be seen that the oil discharged from the pump flows through a horizontal length of pipe about 60 feet long, and returns to the suction-tank by another horizontal length about 12 feet above it. For accurate timing of the quantity discharged into the weighing-tank, a rocking shoot is fitted to the latter, so as to divert the current from the suction-tank to the weighing-tank very rapidly and without splash. The circulation through the coils is maintained by a small auxiliary motor-driven centrifugal pump, so arranged that a circulation of hot or cold water can be maintained through the coils. The frictional resistance is estimated by measuring the fall of pressure over a 5-foot length of pipe situated at such a distance from the inlet as to secure steady conditions. For the purpose of measuring the fall of pressure, a sensitive mercury tilting gauge was used, by means of which pressure differences as small as 0·001 lb. per sq. inch could be detected. The gauge is fully described below, p. 65. To prevent radiation-losses the pipes were encased in wooden troughs filled with cork dust.

The Quantities Measured in the Experiments.

These were:—(1) The mean velocity of flow through the pipes. For this purpose the amount of oil passing through the pipes in a given time was weighed on an Avery weighing-machine, and the mean rate of flow during the time determined from the known density of the oil. In the majority of experiments the time was measured by an electrical chronograph, operated by the arm of the balance.

(2) The temperature of the oil passing through the experimental portion of the pipes. This was determined by placing an iron-eureka thermo-junction in the centre of the pipe at the discharge end of the experimental portion, and a second similar junction at a distance of about 8 feet behind the first, so that any cooling or heating of the oil passing along the pipe could be detected. To provide against the possibility of loss of heat to the walls, due to inefficiency of the lagging, a length of 30 feet of the pipe, including

the experimental portion, was wound with eureka-resistance wire, and connected to the electric mains through an adjustable resistance; by regulating the resistance any loss of heat to the walls could be compensated.

(3) The fall of pressure along the experimental portion (see above).

Results of the Experiments.

Observations on Mexican Oil in a 4-inch Pipe.

The tanks were filled with the Mexican oil at the end of September, 1913, and during the next four weeks a series of preliminary observations was made for the purpose of testing and improving methods of observation. It was found that the friction in the centrifugal pump was higher than had been anticipated, and that as a consequence the temperature of the oil in the discharge-pipe was appreciably higher than in the suction. The maximum velocity of flow for the oil used, which was much more viscous than any of the other samples, was about 1·5 feet per second. In the first series of experiments consistent results were not obtained, and the cause of this was traced to irregularities of temperature in the flow. This was done by exploring the cross-section of the pipe with thermo-junctions, when it was found that the temperature in the neighbourhood of the walls was in nearly all cases lower than that at the centre, and, further, when the oil was artificially heated, this difference was still considerable, owing to the difficulty of clearing the colder layers of oil from the walls. The effect of this was that observations taken with a rising temperature were not in agreement with those taken with a falling temperature. Ultimately, by careful regulation of the heating coil on the outside of the pipe, this trouble was eliminated, and consistent results were obtained.

On account of the frictional heating in the pump referred to above, it was found that the arrangements for cooling the oil to the lowest temperature required were inadequate. To remedy this defect, a special form of radiator was designed and constructed. On trying this it was still found impossible, in the case of the Mexican oil, to procure lower temperatures than about 70° F. This was due to the fact that the effect of any considerable reduction in temperature, due to the radiator, increased the viscosity, and therefore the frictional work in the pump, to a corresponding extent, and thus the temperature of the outflowing oil was not materially reduced. These alterations occupied about three

months, and it was not until early in February, 1914, that a satisfactory set of observations on the Mexican oil was obtained. These observations are plotted in fig. 7, curve A, in which the ordinates of the points indicated by a circle are the values of the pressure-drop in pounds per sq. inch per foot run (P), divided by the mean velocity in feet per second (V), and the abscissæ are the corresponding temperatures in degrees Fahrenheit. As was expected, the flow in all cases was stream-line in character, so that the ordinates of the curve in fig. 7 are strictly proportional to the viscosity of the oil. This may be shown as follows. From the ordinary theory of stream-line flow in a pipe we have $PV = 2\eta/9gd^2$ where η is the coefficient of viscosity, and d the diameter of the pipe. Thus if we know η, we can calculate P/V. The values of η were determined by the use of a Redwood viscometer for specimens of the oil taken from the tank during the flow experiments. The viscosity η is connected with the time of flow T seconds observed in the viscometer experiments by the equation $\eta/\rho = AT - B/T$, where for the no. 1 type of instrument

$$A = 2{\cdot}80 \times 10^{-6}, \quad B = 1{\cdot}85 \times 10^{-3}$$

and for no. 2 type

$$A = 2{\cdot}91 \times 10^{-5}, \quad B = 1{\cdot}29 \times 10^{-3}$$

(See Part II.)

In the experiments with the Mexican oil, a Redwood No. 2 instrument was used throughout, and T varied approximately from 1000 to 100 seconds as the temperature changed from 70° to 140° F. Thus the term AT for the most rapid flow is about $2{\cdot}9 \times 10^{-2}$, while B/T is $1{\cdot}29 \times 10^{-4}$, and over most of the range we may neglect B/T, and write $\eta = AT = 2{\cdot}91 \times 10^{-5}\rho T$. Thus for this case we have

$$\frac{P}{V} = \frac{2 \times 2{\cdot}91 \times 10^{-5}\rho T}{9gd^2}$$

T being the time of flow observed at temperature t. Values of P/V were calculated from the viscosity measurements in this manner, using where necessary the more exact value of η/ρ involving the term B/T.

On comparing these values with the actually observed values obtained in the friction experiments, it was found at first that there was an appreciable discrepancy, the cause of which was ultimately traced to the fact that the calculated values of P/V were obtained from the results of viscometer experiments on samples of oil which had not been taken from the discharge pipe during the experiment and tested forthwith. When this precaution was observed, it was found that the agreement of the observed

and calculated values of P/V was quite satisfactory. In fig. 7 the values of P/V calculated from the viscometer experiments are plotted, the points being indicated by a cross (+), and for the purpose of illustrating the above-mentioned discrepancy, the calculated values of P/V from the samples tested some months earlier are also plotted, these points being indicated by a double cross (‡‡). It will be seen that in the former case the agreement is satisfactory, and indicates that the flow was stream-line in character up to the

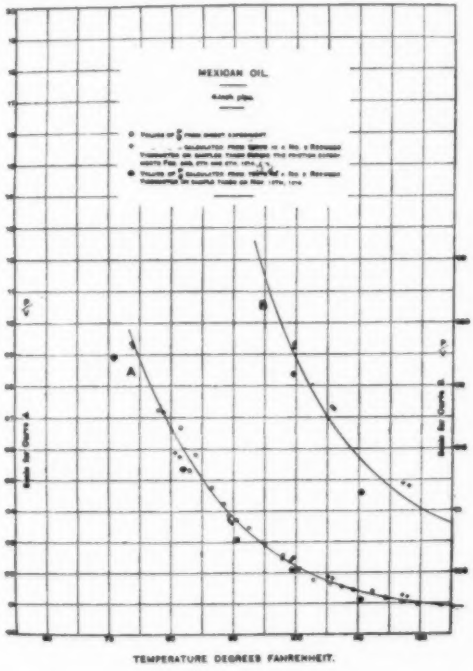

FIG. 7.

highest velocities obtained, which were 1·41 feet per second for the Mexican oil.

To give a clearer idea of the order of accuracy obtained, the lower part of curve A has also been plotted to a larger scale in curve B.

The variation in the viscosity of Mexican oil with time is discussed more fully in Part II of the Report. This variation was

not noticed, at any rate to an appreciable extent, in any of the other oils experimented with, though there was evidence in the case of the Texas oil that some of the lighter constituents may have been distilled off at the higher temperatures.

Observations on Scotch Shale-oil in 4-inch Pipe.

It is known that stream-line flow in a fluid breaks down for a critical value of the velocity which makes the quantity $\rho Vd/\eta$ approximately equal to 2500. With the shale-oil the viscosity is such at a temperature of 60° F., that this critical case occurs at a speed of about 1 foot per second in the 4-inch pipe, and becomes eddying or turbulent for all higher speeds up to 3·5 feet per second, which was the maximum obtained.

For these observations the values of the ordinates in the curve of plotted results have been taken to be the values of f in the equation

$$h = 4f \frac{L}{d} \frac{V^2}{2g}$$

where h = loss of head due to friction in feet of the oil,
L = length of experimental pipe in feet,
d = diameter in feet,
V = mean velocity of flow in feet per second.

The abscissæ are the corresponding values of $\rho Vd/\eta$ where ρ is the density, and η the coefficient of viscosity of the oil.

The plotted results are given in fig. 8.

It may be mentioned that the curve is not in strict agreement with the curve obtained from the National Physical Laboratory experiments on air and water, as it should be. The cause of the discrepancy appears to lie in the fact that the actual values of the pressure drop were as low as ·03 inch of water, whereas the pressure to which the glass manometer was exposed was that due to 12 feet of the fluid, and therefore any small distortion due to this pressure would have a relatively large effect. That such an assumption is justifiable will be seen from the results of the experiments on the same oil in a pipe 3 inches diameter described in the next section.

Observations on Scotch Shale-oil in 3-inch Pipe.

In these experiments, for the reason stated at the conclusion of the last section, the length of the experimental portion was made 168 inches, which was the maximum which could be obtained without including a joint. By this means the pressure drop in the experimental portion was increased in the ratio of approximately eight to one, so that the effect of any distortion such as

that discussed above could be neglected. The range of speed obtained was from 0·5 to 5 feet per second. On plotting the results for this pipe (see fig. 8) it was found that these agreed with the known resistances in the case of air and water within an amount corresponding with the limits of accuracy of the present experiments. The results are shown in the following table:

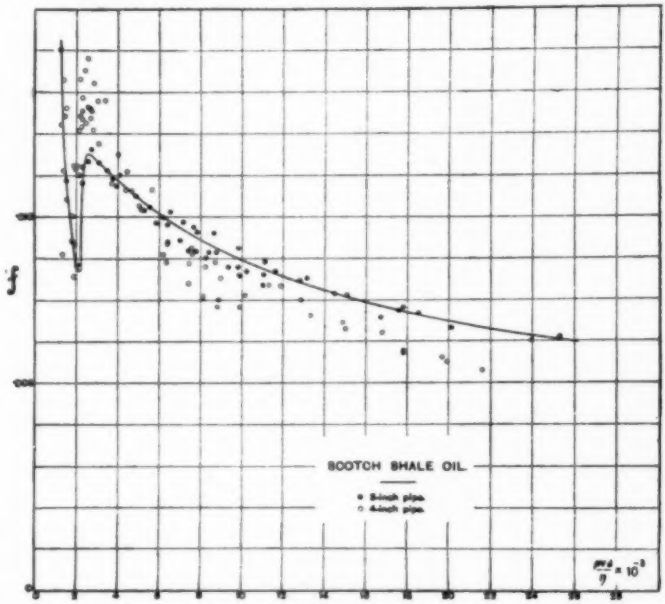

FIG. 8.

VISCOSITY &c., OF MIXTURES OF MEXICAN AND SCOTCH SHALE-OIL.

Percentages.		Density at 60° F.		Viscosities.			Flash-point °F.
Scotch Shale.	Mexican.	lbs. per cub. ft.	grams per cub. cm.	Temp. °F.	Viscosity.	Viscosity at 60° F.	
100	0	53·6	·8585	32	$0·217 \times 10^{-3}$	$0·115 \times 10^{-3}$	237
90	10	54·1	·8660	32	0·293 ,,	0·155 ,,	212
80	20	54·6	·8745	32	0·438 ,,	0·221 ,,	201
70	30	55·15	·8835	32	0·851 ,,	0·326 ,,	186
60	40	55·75	·8930	32	2·075 ,,	0·511 ,,	179
50	50	56·25	·9010	32	4·355 ,,	0·865 ,,	167
40	60	56·8	·9095	32	12·2 ,,	1·485 ,,	151
30	70	57·5	·9190	37	32·7 ,,	2·61 ,,	154
20	80	57·9	·9280	45	28·2 ,,	5·74 ,,	148
10	90	58·4	·9355	50	38·4 ,,	15·3 ,,	143
0	100	58·95	·9440	55	110·0 ,,	72·0 ,,	145

Setting-points, approximately: Mexican, 45° F.: 90 % Mexican, 40° F.: 80 %, 35° F.: 70 %, 32° F.: 60 % and less, below 32° F.

General Conclusion.

The general conclusion derived from these experiments is thus seen to be that the relations which hold for the flow of oil in a pipe are exactly those applicable to the flow of any other viscous fluid. So long as the value of $\rho Vd/\eta$ is less than 2500 (which was the case for all the oils tested except the Scotch Shale at the higher temperatures), the flow is stream-line in character, and the pressure drop is given by

$$\frac{P}{V} = \frac{2\rho}{9gd^2}\left(AT - \frac{B}{T}\right),$$

where A and B have the values stated on p. 50, and ρ is the density of the oil in pounds per cubic foot. For values of $\rho Vd/\eta$ greater than 2500 the flow is turbulent, and the known relation for turbulent flow can be applied (see p. 52) when the condition of surface-roughness of the pipe is known.

Part II.

Physical Constants of the Oils.

Introduction. The second part of the research was planned to include the determination of certain of the physical constants of the oils employed. The measurement of the density and viscosity of the oils over a range of temperatures, and the observation of the flash-point were carried out. Corresponding measurements were undertaken for a series of mixtures of the oils; some interesting results were obtained in this connection, and these will be referred to in due course. Further points dealt with included some tests on the separation of mixed oils on prolonged storage, and the determination of the lowest temperature at which an oil will evolve sufficient inflammable vapour to "flash." In the course of a series of determinations of the viscosity of Mexican oil, it was noticed that considerable discrepancies occurred among measurements taken under apparently similar conditions. The differences observed were considerably greater than could be accounted for by errors of experiment, and an investigation into the reason of these variations was accordingly undertaken. Although it has not been possible to carry the research far enough to obtain a complete explanation of the causes of the phenomena, some interesting results have been obtained, which throw light on the question, and these will be discussed later. A brief account of the methods employed, and the results arrived at, in each of the

determinations of constants or special investigation above referred to will now be given.

Density. The determination of the densities of the oils calls for little comment. The ordinary specific-gravity-bottle method was employed, and determinations were made at four temperatures over the range 32° to 140° F. for each oil. The results show that for each of the oils the decrease in density is proportional to the increase in temperature.

Viscosity. The viscosity was determined on either of the two types of Redwood viscometer. The range of viscosities of the oils dealt with was considerable, varying from about 30 seconds on the no. 1 instrument to over one hour on the no. 2 type. The determinations were made at every 10° from 32° F. to 140° F.,

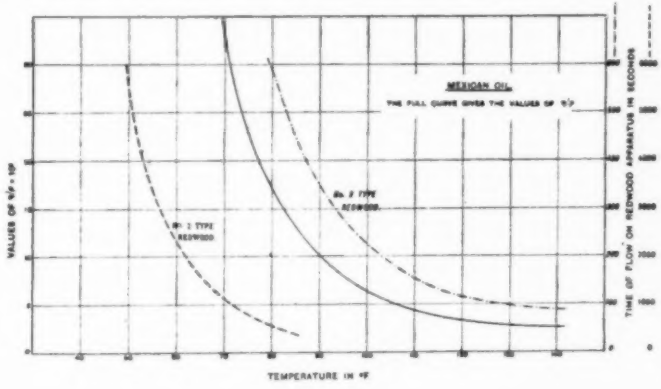
MEXICAN OIL
THE FULL CURVE GIVES THE VALUES OF ν/ρ
No. 2 TYPE REDWOOD
No. 1 TYPE REDWOOD
VALUES OF ν/ρ - 10
TIME OF FLOW ON REDWOOD APPARATUS IN SECONDS
TEMPERATURE IN °F

Fig. 9.

except in one or two instances in which the oil had a setting-point above 32° F. When the time of outflow of 50 cc. of the oil exceeded about 15 minutes on the no. 1 Redwood viscometer, the determination was carried out on the no. 2 or Admiralty fuel-oil type of instrument. The rate of outflow in the case of the latter instrument is roughly ten times that of the earlier pattern. A more exact correlation of the results is obtained by converting the experimental values into absolute viscosities. The relation between the true viscosity of a liquid and its time of outflow on the Redwood viscometer is given by the relation,

$$\eta/\rho = AT - B/T$$

η and ρ being the true viscosity and density of the oil respectively, T the time of outflow, and A and B instrument-constants. The

values of A and B, determined at the laboratory for the instruments used in the present work were :—

$$\text{No. 1 type} \begin{cases} A = 2{\cdot}80 \times 10^{-6} \\ B = 1{\cdot}85 \times 10^{-3} \end{cases}$$

$$\text{No. 2 type} \begin{cases} A = 2{\cdot}91 \times 10^{-5} \\ B = 1{\cdot}29 \times 10^{-2} \end{cases}$$

These constants were obtained by the comparison of a large number of Redwood times with the values given by experiments on the same oils with a capillary viscometer of the type employed by Thorpe and Rodger in their work on the relation between viscosity and chemical constitutions. A full account of these experiments is given in a paper on Viscometry published in vol. xi of the "Collected Researches" of the National Physical Laboratory.

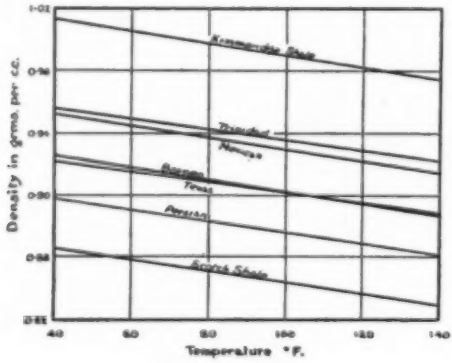

FIG. 10.

The most marked feature observed on plotting the results of the viscosity-determinations as temperature-viscosity curves is the very considerable rate of change of viscosity with temperature exhibited over the lower ranges. This amounts to several per cent. per 1° F. for some oils in the neighbourhood of the air-temperature and lower. In view of this, particular attention was paid to maintaining the temperature of the oil in the viscometer as constant as possible during the course of a test. The difficulty here experienced is due to the impossibility of stirring the oil during the course of an experiment, and can only be surmounted by keeping the water-bath temperature very steady. In general the temperature of the oil was maintained within 0·1°

for temperatures up to 90° F. and within 0·2° or 0·3° at higher values. Consistent results were obtained on repetition of the tests, except in the case of Mexican oil. The reason of this is dealt with elsewhere.

Flash-point.—The flash-point of each oil was determined on the Gray apparatus, and the values obtained ranged from 140° to about 240° F. The procedure for carrying out a flash-point determination at high temperatures (above say 120° F.) is not standardised as in the case of the Abel test, and in ordinary practice no attempt is, as a general rule, made to obtain the result to nearer than 5° F. In the present investigation the method was modified as follows. A rough determination was first made, and in the ensuing experiments the oil in the flash-point apparatus was heated to within about 20° of this preliminary value at a fairly rapid rate. The rate was then reduced considerably, and the test-flame was depressed at each 2° rise in temperature until a flash was obtained. The rate of rise in the final stages should not exceed 3° to 4° per minute. Consistent results were readily obtained in this way, and the method is justifiable in that a means of stirring is provided for both the oil and the vapour-space during the intervals between the depressions of the test-flame.

The lowest flash-point noted for the oils under test was that of the Mexican oil, which flashed at 145° F. This oil was further investigated at a later stage to ascertain whether larger quantities of the oil, of the order of 5 gallons, would yield sufficient inflammable vapour to flash, at a temperature lower than that indicated by the ordinary flash-point apparatus of small capacity. Evidence was obtained showing that a reduction of flash-point to the extent of a few degrees could be produced, but the difference does not appear to be sufficiently great to necessitate any modification of the usual test.

Tests on Mixtures of Oils. One of the subsidiary matters upon which information was desired was the question of the connection existing between the physical constants of a mixture of oils and those of its components. In order to investigate this, several series of mixtures of oils were made up, and their constants determined as detailed above. For each pair of oils dealt with, the composition of the successive mixtures was changed by 10 % over the range from 10 % to 90 % of either component. Data are thus available for the construction of curves representing the relation between the properties and composition of a mixture of two oils.

The properties investigated were (*a*) the density at 60° F.,

(*b*) the viscosity at two temperatures, 32° and 60°, and (*c*) the flash-point. In the event of the mixed oils setting above 32° F. the viscosity was determined at the lowest point convenient instead of at 32°. Fifteen pairs of oils were tested, and the following remarks based on the results obtained may hence be considered capable of general application.

(*a*) *Density.* In all the cases investigated it has been found that the density of a mixture is proportional to the quantity and density of the constituent oils. Thus if m parts of an oil of density D_1 are mixed with n parts of an oil of density D_2, the density (D) of the resultant mixture is given by

$$D = \frac{mD_1 + nD_2}{m + n}$$

It is thus an easy matter to calculate the density of a mixture of oils from a knowledge of the proportion and density of its components.

(*b*) *Viscosity.* There appears to be no simple law connecting the viscosity of a mixture with that of its components, but from an examination of the results obtained it is at once apparent that the addition of an oil of low viscosity to one of high viscosity produces a much larger decrease of viscosity than would result from a law of simple proportion. As an example of this, reference may be made to the case of mixtures of Mexican with Scotch Shale and Borneo oils, when it will be seen that an addition of 10 % of these caused the viscosity of the Mexican oil to fall from $72{\cdot}0 \times 10^{-3}$ to $15{\cdot}3 \times 10^{-3}$ and $18{\cdot}6 \times 10^{-3}$ respectively, the temperature at which the determinations were made being 60° F. in each case. The reduction of viscosity is thus 79 %, and 74 % in the two instances, a result which may be of considerable value in practice.

The effect becomes less marked as the constituent oils become more nearly equal in viscosity, and in some instances, for example, in mixtures of Scotch Shale and Borneo, Texas and Kimmeridge Shale, and Trinidad and Kimmeridge Shale-oils respectively, the viscosities of the mixtures become roughly proportional to their composition. The tendency, however, in these cases is still for the mixture to have a lower viscosity than would follow from simple proportion.

(*c*) *Flash-point.* The effect of adding an oil of low flash-point to one of higher flash is to decrease progressively the flash-point of the mixture as the proportion of the low-flash oil is increased. This would reasonably be expected, but the interesting result brought out by these experiments is that the lowering of the

flash-point is continued beyond that of the added oil. The effect is shown in practically all the cases investigated, and in some instances amounts to about 20° F. Thus it may happen that two oils which individually comply with a specification regarding flash-point, may, when mixed in certain proportions, produce an oil which flashes below the specified temperature-limit.

Separation of Mixed Oils by Storage. A point of some importance if mixtures of oils from different sources are to be used to any large extent commercially, is the consideration as to whether any separation of the constituents takes place on prolonged storage. The question was tested by direct experiment in the following way. The mixtures of oils were stored in tall glass jars of about 4½ litres capacity. The jars were provided with taps at four levels as shown in the diagram; these served to withdraw samples at the end of the storage-period. The oils were stored in these jars for 212 days, being left undisturbed in a room whose temperature was not subject to sudden fluctuations. At the end of the time samples were withdrawn from the four levels, and the viscosity and density of each were determined. The samples were withdrawn slowly, and in the order (1), (2), etc., to avoid unnecessary disturbance of the bulk of the oil. The volume withdrawn was the minimum necessary for carrying out the tests.

Four representative mixtures were investigated, and the results obtained are shown in the following table:—

Sample.		A.	B.	C.	D.
Composition of Mixture.		Equal parts Scotch Shale and Texas.	Equal parts Scotch Shale and Trinidad.	Equal parts Scotch Shale and Mexican.	Two parts Scotch Shale and one part Mexican.
Density at 60° F.	Level 1	0·8874	0·9042	0·9017	0·8860
	„ 2	0·8874	0·9039	0·9016	0·8860
	„ 3	0·8874	0·9041	0·9014	0·8868
	„ 4	0·8873	0·9041	0·9014	0·8883
Viscosity at 60° F. ($\times 10^3$)	Level 1	0·352	0·545	0·991	0·344
	„ 2	0·352	0·545	0·991	0·343
	„ 3	0·355	0·544	1·021	0·530
	„ 4	0·360	0·544	1·022	0·445

Considering first the results for the densities, it will be seen that Mixture D (two parts of Scotch Shale and one part Mexican oils) is the only example which shows any evidence of increased density in the lower layers: in each of the other mixtures the densities are practically constant for the different levels.

Referring next to the viscosity-readings, Mixture B (equal

parts of Scotch Shale and Trinidad oils) shows no change of viscosity with level, thus indicating that in this case no separation has taken place. Mixtures A and C (equal parts of Scotch Shale with Texas and Mexican oils respectively) show a slight progressive increase of viscosity with depth, which points to a slight separation of the constituents. This, however, is not sufficiently marked to produce changes in the density. The viscosity-results for Mixture D confirm the conclusion drawn from the density-results to the effect that some separation has occurred. The sample from level 3 has the highest viscosity, although of intermediate density. The actual amount of separation is probably small, the increase of viscosity from $0{\cdot}34 \times 10^{-3}$ to $0{\cdot}53 \times 10^{-3}$ being associated with quite a small change in the composition of mixtures of Scotch Shale and Mexican oils. The conclusion which may be drawn from these tests is that any separation which may take place when mixed oils are stored in bulk is comparatively small, and is not sufficient to necessitate special precautions being taken in practice.

On the Lowest Temperature at which an Oil will evolve sufficient Inflammable Vapour to "Flash."

The determination of the flash-point of the oils has been referred to earlier, and at the same time the question of the influence of the size of the flash-point apparatus upon the result obtained was raised. It has been pointed out elsewhere that the "flash-point" of an oil cannot be considered to be a definite physical constant, but must necessarily depend to a certain extent on the apparatus employed in its determination; and from this point of view it is at once evident that it is important to ascertain whether the flash-point obtained by the usual type of test-apparatus affords any real indication of the flash-point of the oil stored in bulk. The experiments which will now be described were planned to test this, and may be considered as carried out on a scale intermediate between that of the usual laboratory determination and tests on storage-tanks, which for obvious reasons would be impracticable.

The apparatus employed consisted of a cylindrical cast-iron vessel of about 5 gallons capacity. This vessel was wound externally with an electric heating-coil, and was covered with a layer of insulating material 2 inches thick. The heating-coil was wound in three sections, and by suitably connecting these to the supply-circuit, the oil could be heated at any desired rate. A

cover provided with several apertures was bolted to a flange on the upper edge of the vessel. A motor-driven propeller, carried in a brass tube extending to the bottom of the vessel, was used to circulate the oil. In most experiments this stirrer was run continuously, the rate being adjusted to keep the temperature of the oil constant throughout its bulk, but at the same time to avoid any violent agitation of the surface such that bubbles or froth might be produced. Apertures were provided to permit the introduction of thermometers into the oil. Simultaneous readings of these thermometers when placed at different points in the oil, and at different depths of immersion, showed that, at temperatures above 100° F., the temperature was the same to within 1° F. A glass window was provided through which the surface of the oil could be observed, and, in some instances, the blue flame obtained when the oil "flashed" could be seen to travel very slowly across the oil-surface. In others the progress was more rapid, and the "flash" manifested itself by a more or less violent escape of gas from the "safety-valve" fitted to the apparatus. This valve consisted of a flat metal disc covering a 2-inch hole in the cover. When the pressure within the apparatus rose sufficiently to overcome the weight of the plate, the latter lifted and allowed the gas to escape. Guides and a stop were provided to restrict the motion of the valve-disc. Ventilation of the vapour-space above the oil was obtained by the introduction of a tube through which air could be pumped. A vent-pipe was also fitted. It was possible rapidly to clear the space above the oil from burnt gas by a few vigorous strokes of the pump or to pass a very slow current of air over the oil continuously. Natural ventilation was also obtained by removing the valve, and opening another aperture in the cover which was normally kept closed.

The ignition of the oil-vapour was brought about by either of two methods. The first was by the use of a short spiral of platinum wire maintained at a white heat by an electric current when a key was depressed. The other method was to use a small gas-flame, which was inserted when desired through an aperture which was usually kept closed.

Mexican oil was used throughout the experiments about to be described, and its flash-point, taken by the usual method on the Gray flash-point apparatus, was 145° F. The oil used was tested at intervals during the course of the experiments, and no appreciable change was noted. The procedure adopted in these experiments was to heat the oil at a fairly rapid rate to about 120° F., and then

to continue the heating very slowly, applying the test-flame at intervals of 1½ to 2 minutes. The rate of heating was such that the rise of temperature was not greater than 1° F. in the 2-minute interval. The heating was stopped as soon as a flash was obtained.

Acting in this way the oil was found to flash at 143° F. in the first experiments, the gas test-flame being used. The vapour-space above the oil was ventilated by blowing air through it after each application of the test-flame, and sufficient time was allowed for vapour to accumulate before the test-flame was again applied. Some experiments were made to test the effect of varying this time interval. For this purpose the oil was maintained constant at 144° F., and the following results were obtained:—

1. Vapour collecting for 1½ minutes: a very feeble flash was sometimes obtained, while in other cases no flash resulted from the application of the test-flame.

2. Interval increased to 2 minutes: a moderate flash was generally obtained.

3. For longer periods of 3 to 6 minutes the flash was very vigorous, and occasionally violent.

These observations show that the flash-point obtained with this apparatus depends upon the length of time during which the vapour given off from the surface of the oil has been allowed to accumulate. (This, of course, is also a property of the ordinary type of flash-point apparatus.)

Tests were next made with the oil at a slightly lower temperature, the other conditions remaining as before. At 141° F. no flash was obtained under 4 or 5 minutes interval, and the flashes then started were very feeble, and frequently did not travel all over the oil-surface. To obtain a moderately vigorous flash with certainty, a period of at least 10 minutes was necessary. Further tests were carried out with the oil maintained at from 139° to 140° F. No flashes could be obtained at this temperature even when the vapour was allowed to accumulate for 15 to 20 minutes. The flash-point of the oil is thus not lower than 140° F.

Variations in the conditions of the above experiments were next tried. The gas-flame used for ignition in the above tests was about ⅜ inch in length, and the diameter of the jet from which the gas issued was slightly under $\frac{1}{16}$ inch. Increasing this to double the size had no appreciable effect on the flash-point.

The hot-wire ignition device proved to be much less effective than the gas-flame. It was found that an oil-temperature of 152° F. was necessary before a flash could be started; it was however interesting to note that the flash, when started by the hot wire,

was always very vigorous, indicating that a large amount of inflammable vapour had collected. No feeble flashes such as occurred at temperatures about 141° or 142° F. with the gas test-flame were obtained with the hot-wire ignition. The use of the latter was discarded in the further tests quoted.

Experiments were made with the oil unstirred: the effect was an apparent raising of the flash-point to about 145° F., at which temperature feeble flashes were obtained. The slight movement of the oil-surface in the ordinary case probably promotes a more rapid evolution of vapour.

In the experiments dealt with up to now, the vapour-space above the oil was 3 inches in depth. The effect of altering this space was next investigated. Oil was run out of the apparatus until the depth of the vapour-space was approximately doubled. Flashes were obtained in the neighbourhood of 151° F., and were much more violent in nature than usual, doubtless owing to the larger amount of vapour undergoing combustion; it was also noted that the hot wire became almost as effective as the gas-flame, flashes being obtained by its use at 154° F. Reduction of the vapour-space to 2½ inches gave flashes at 142° F. of a similar nature to those with a depth of 3 inches. Very slow but continuous ventilation of the vapour-space by means of an air-current raised the flash-point to over 160° F. In a similar way natural ventilation of the space by leaving open several apertures in the cover caused the oil to flash at temperatures from 155° to 159° F.

The experiments detailed above lead to the conclusion that the Mexican oil will not yield inflammable vapour in sufficient quantity to flash at temperatures lower than 140° F., the corresponding flash-point on the Gray apparatus being 145° F.

Investigation on the Viscosity of Mexican Oil.

The remaining investigation to be dealt with in this paper was not included in the original plan of the research, but arose in the course of some determinations of the viscosity of Mexican oil, in which it was found that considerable discrepancies occurred between results taken under apparently similar conditions. These differences were much greater than could be accounted for by experimental error, so that it was desirable that the matter should be further investigated. Repeated observations on any one sample gave results which agreed closely among themselves, but if re-tested after an interval of a day or two a different set of values was obtained.

A continuous change appears to be going on in the constitution of the oil, probably an "association" of molecules to form new molecules of heavier molecular weight. This change is dependent on time, and is, furthermore, a function of the temperature to which the oil is subjected. Some of the experimental evidence of this dependence of viscosity, and, by inference, of constitution, upon both time and temperature will now be given.

(1) A sample of oil was divided into two portions, and was placed in stoppered bottles. The first of these was stored in an ice-safe for six days, while the second was kept for the same period in a hot room at a practically constant temperature of 93° F. The two oils were then removed, and the viscosity at 60° F. determined in each case. That stored at 32° F. had increased by 20 % of its original value at 60°, while that maintained at 93° had similarly decreased by about 11 %.

(2) The effect of increasing the time of exposure to the low temperature was next ascertained, and a sample was stored for 120 days; at the end of this time the viscosity at 60° F. had risen to over $2\frac{1}{4}$ times the original value.

(3) Another sample was heated to about 150° F. for roughly 40 hours, extended over a period of some 10 days; the viscosity at the end of this time was reduced to about half the initial value.

(4) The oil referred to in § 2 above, which had been kept at 32° F. for a period of 120 days, was divided into several portions; these were heated to a temperature of 100° F. for various lengths of time, and their viscosities at 60° F. determined. The high value above noted was rapidly reduced, and exposure to 100° F. for about two hours was found to reduce the value to the original figure. Prolonged heating at a still higher temperature would probably have reduced the viscosity still further in accordance with the result noted in § 3.

(5) A possible explanation of the above observations would have resulted from the presence of minute solid particles in suspension in the oil, and a test was accordingly made to ascertain whether such particles were present. Some of the oil under consideration was allowed to stand for a period of 34 days in a tall vessel at the air-temperature (this varied slowly between 45° and 60° F). It is probable that any solid matter in suspension in the oil would separate to some extent. Samples taken from the top and bottom levels of the oil showed no appreciable difference in viscosity. Tests were at the same time made to trace corresponding changes in density; such changes if they existed were so small as to remain undetected.

The conclusion to be drawn from these investigations is that Mexican oil is subject to a change in viscosity with time: the change is in the nature of an increase if the oil is kept at a low temperature, but the normal value may be again obtained by exposure to a high temperature for a comparatively short period. The practical bearing of this is apparent, and due precautions should be taken in instances where Mexican oil is stored in outside tanks during the winter months, or in cold climates. It might further be remarked that the Mexican oil was the only oil investigated which showed this "hysteresis" phenomenon; the other oils dealt with in the main research were also examined, but gave no evidence of undergoing the change which characterised the Mexican oil. The magnitude of this effect may be greatly reduced, in fact it was rendered practically negligible, by adding a low viscosity oil to the Mexican oil; this was shown experimentally in a test carried out on a 10 % mixture of Scotch Shale with 90 % of Mexican oil.

Conclusion.

The series of investigations which form the bulk of the second part of this paper make it clear that much work remains to be done in connection with the chemistry and physics of those complex hydro-carbons which are the components of fuel-oils, in order that a clearer idea of their constitution may be obtained. The effect dealt with in the last section, for example, is one which can only be fully explained when a more exact knowledge of the complex molecular structure of heavy oils is available. It is however from a careful study of such facts as these that this structural knowledge may be obtained, and it is probable that much valuable information would repay a careful and systematic investigation of allied phenomena.

Description of the Tilting Manometer mentioned as used in the Experiments. By Mr. J. R. Pannell.

The original form of the pressure-gauge described below was designed and used by Dr. A. P. Chattock (*Phil. Mag.*, Jan., 1901), and has since been described by the present writer in an improved form (*Engineering*, vol. xcvi, pp. 343, 344 [1913]). The gauge was designed to measure small air-pressure differences, and was modified as shown in the figure to measure small water-pressure differences. For measuring oil-pressure differences, an intermediate vessel is used, having a diameter of about 1½ inches at the water-oil meniscus. A

relatively large diameter is necessary to allow free motion of the fluid in the connecting tubes.

The gauge consists of a glass U tube of somewhat unusual form, mounted on a metal tilting-frame. The glass work is carried by corks, which should be bored eccentrically to give a small amount of adjustment. The pressure difference is measured by tilting the U tube, instead of measuring the displacement of the surfaces, errors due to capillarity being thus avoided. The lower half of the end cups is filled with mercury, the space above, and the connecting tubes being filled with water.

It will be seen that above the end cup on the right in the figure is a third vessel into which projects a tube from the cup below. The upper part of this vessel is filled with oil to some point between the top of the central tube from the lower cup and the connecting tube which projects to the right, the tap in the horizontal limb being closed.

A clear mineral oil of Russian origin has been found reliable, but any transparent oil which is inert in water would probably be suitable. If the right end of the gauge is now depressed, and the tap opened, there will be a flow from left to right and up the tube into the upper vessel, a curved surface of separation between the oil and water being thus obtained at the top of the central tube.

This surface is illuminated by a small mirror, and its position observed by a microscope. A displacement of the mercury surface causes a change of position of this separation-surface, and the accuracy of the gauge depends on the accuracy with which the position of the surface can be adjusted. The gauge is rendered portable by means of the tap in the horizontal limb, and there is a ground joint to facilitate cleaning. This joint should be treated with jelly, and for very high pressures some form of clip may be necessary to prevent the upper portion blowing out. A suitable jelly can be made by heating 20 parts of gelatine and 10 parts of glycerine in 70 parts of water, a few drops of carbolic acid being added to preserve it. The jelly can be applied by warming the glass.

The metal frame is in two parts. The upper part, which carries the glass work, rests upon three hardened steel points in the lower part, and is held in place by a spring at one end and a guide at the other. One of the points can be raised or lowered by rotating the hand-wheel, causing the U tube to tilt. The whole frame is supported on three levelling screws.

The method of using the gauge is as follows. The reading of the hand-wheel for zero position of the bubble having been observed, the

pressure difference is gradually applied, the movement of the separation-surface being corrected by rotating the hand-wheel.

It is not desirable to allow any very considerable excursion of the bubble or a change of zero may be caused, or in extreme cases the surface would be ruptured. A thin layer of wax on the outside of the inner tube will enable the bubble to stand a large displacement before rupture actually occurs.

When the pressure difference has been applied, the reading of the hand-wheel for zero position of the bubble is again observed, the head being obtained from the difference of the two readings.

If the full pressure difference is applied at once, the tap in the

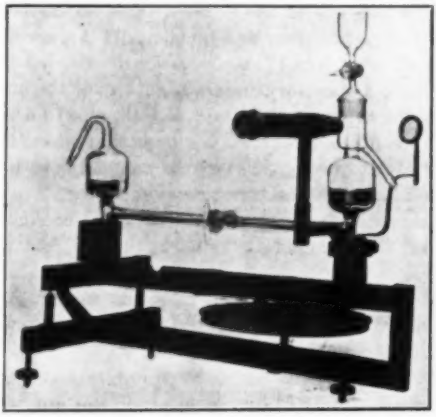

FIG. 11.

horizontal limb can be partly closed till the hand-wheel has been set at approximately the proper value.

The dimensions of the gauge are such that the difference of level of the two cups produced by one turn of the hand-wheel is 0·065 inch. The gauge is sensitive to a movement of one-thousandth part of a revolution of the hand-wheel enabling the pressure difference to be read to a head of 0·00006 inch, or since the fluid is mercury in water (density 12·0) about 0·00002 lb. per sq. inch. This figure was often very considerably increased in measuring oil-pressure differences, owing to the high viscosity of the oil. The gauge will measure pressures up to about 0·3 lb. per sq. inch.

DISCUSSION.

The President said that during the comparatively short time which had elapsed since the foundation of the Institution, they had been conspicuously successful in regard to the high standard of the geological, engineering and chemical papers which had been read. He did not wish to make any invidious comparisons, but he thought all the members would agree with him that they had never had, and, however long they might continue to attend the meetings, probably never would have, a better address of its kind than that which had just been given.

It conveyed in a concise and lucid manner information, hitherto unobtainable, which was of the greatest value to all concerned in the technology of petroleum; and incidentally it showed what very important work was being unostentatiously carried out at the National Physical Laboratory under the control of the distinguished Director. In the interests of petroleum technology he ventured, on behalf of the members, to express the hope that when, through the efforts of the Allied Forces, this terrible war had been brought to a successful issue, it might be found possible to continue and extend the very interesting and valuable investigation on the lines referred to in the concluding remarks which had fallen from Dr. Glazebrook.

Dr. G. T. Beilby thought the members would agree with the President that the paper was an epoch-making one, not only from the general technical point of view, but also from the point of view of the Institution. It was no small thing to have obtained the permission of the Lords Commissioners of the Admiralty for the publication of the results given in the paper, and it was a further matter for congratulation that Dr. Glazebrook and his able assistants had been able to lay before the Institution, in such an extremely lucid and comprehensive way, the fruits of many months of work.

Those who were interested in the theoretical side of the subject-matter of the paper were naturally attracted by the last point which the Authors had dealt with as one of very considerable interest, namely, the curious result obtained from heating or cooling Mexican oil, and its temporary effect upon the viscosity.

When Lord Fisher's Commission on Oil and Engines for the Navy was sitting some years ago, those questions were very much before it. That curious feature of Mexican oil was then recognised, and a number of experiments, independent of those of the authors, were made on the point. From a theoretical point of

view the idea that the gradual change in viscosity after heating or cooling resulted from a direct re-association of the chemical molecules was a very fascinating one, but, although admitting this, he thought it was necessary to take into consideration that the substance which was being dealt with was not a simple or homogeneous one. It was really an exceedingly complex mixture, not only of pure hydrocarbons, but also of a variety of substances of very complex constitution which the chemist had no means of isolating.

He thought it was worth while drawing attention to the fact that the oils that were experimented with in the paper were not of an equal purity. For instance, he presumed the Scotch oil referred to was a partially-refined oil.

Mr. Higgins said it was supplied by the Admiralty as fuel oil. He understood that it was crude oil such as the Admiralty used in very large quantities for fuel-purposes. It was not such as would be called refined oil.

Dr. Beilby desired to point out that an investigation on hydrocarbons in their purest state would be necessary before it was possible to settle the question of molecular association. There could be no doubt that such an investigation would be of the very highest interest. Practical oil-refiners were aware that those portions of American oils and also of Scotch oils which are normally obtained as crystallised paraffin can, under certain conditions, be obtained in a viscous gelatinous form; and something of the same sort might be happening in the case of the Mexican oil, in which it might be that, when cooled after heating, a kind of gelatinisation took place. He hoped that point would be further developed by other workers.

Professor Cadman said the Institution was to be congratulated upon having received such a valuable paper from so high an authority as Dr. Glazebrook. Papers of this character frequently carried with them a peg upon which a piece of research might be hung, but the present paper seemed to be a veritable cloak-room, containing as it did so many valuable suggestions as to investigations which might possibly be followed. In that cloak-room the tarry pegs, which Dr. Beilby seemed to think bristled with difficulties, still opened up a very great field for chemical investigation.

He was very much interested in the authors' observations upon flash-points, because he had always looked upon flash-point observations as resulting in merely an empirical figure, which depended upon the instrument used, and comparisons were useless unless the determinations had been made with the same instrument. He was a little surprised at the authors' comparison, or attempted

comparison, of flash-points of oil on a large scale with those taken in a standard apparatus.

The flash-point determination was merely a factor of the temperature at which the lower limit of inflammability was reached, and it was important to standardise the procedure, because the state in which the mixture of vapour and air existed seriously influenced the lower limit. The work of Dixon, Wheeler and Dugald Clerk had shown that, by means of agitation, inflammation, or the symptoms of inflammation, might be obtained with a very much less quantity of inflammable gas than when the mixture was at rest. It seemed to him that the way in which observations of flash-points were undertaken needed to be very clearly stated, and that no attempt should be made to make use of figures which had not been very carefully recorded, in the way, for instance, adopted by the authors.

He thought the members were to be congratulated upon having Dr. Glazebrook present with them in the flesh, and hearing from him at first hand details of such an extremely useful piece of research.

Mr. J. E. Hackford, after stating that Mr. J. S. Smith was unfortunately unable to attend the meeting, said he did not propose to make any remarks from the practical engineering point of view, as he was a chemist, and approached the subject from that standpoint. It would be difficult to over-estimate the value of the work accomplished by the authors, and the painstaking and careful way in which their physical tests were carried out deserved great commendation.

It was not his intention to enter into a lengthy discussion as to the ways and means by which those tests were made, but he had met with the phenomenon of hysteresis in the course of his investigations upon Mexican fuel oil and in the course of the manufacture of the same.

As the members were aware, the rapid rise of the Mexican oil fields was phenomenal in the history of oil fields in general. It had been exceedingly difficult to keep pace with the enormous production in the matter of refining plant. Another point was that Mexican oils were typical of the asphaltic oils, and, as they might say that the Mexican oil fields only originated in 1901, the rate of progress of development had been much more rapid than the progress of their knowledge of the chemical constituents of the distinctive fraction of the oil, namely, the asphalt. The same remark applied to the physics of mixtures of the constituents. However, great progress had been made during the last two years, and every effort

was being made to supply a Mexican fuel oil which would not show hysteresis, the results so far being very promising.

He agreed with the statements deploring the lack of scientific knowledge regarding the chemistry and physics of the complex components of fuel oils, and considered that a thorough and systematic effort should be made to improve our knowledge of oils in general, as it was only by so doing that we could hope not only to elucidate the great number of commercial problems which were continually arising, and which often went unexplained, but also to discover new fields of application for present and perhaps as yet undiscovered products.

He desired to ask whether there were any traces of water present in the Mexican fuel oil which had been described, because it had been found that small traces of water very greatly influenced the viscosity. They produced very marked variations according to the temperature at which the viscosity was determined.

Mr. H. Barringer said that, speaking entirely from the engineering point of view, he had listened with the greatest interest to the paper that had been read, and the impression left on his mind was that he wanted to know a great deal more on the subject. It appeared to him that in practice they nearly always exceeded the figure of 2,500 which the authors had given as representing the critical velocity. He had in mind pumps designed for the discharge of 300 tons per hour through a 9-inch pipe, representing a critical velocity of somewhere about 2,500, but in practice these same pumps would have done 500 tons per hour through a 14-inch pipe, which would have brought the figure considerably above the critical stream-flow of 2,500. What had been done wrong here? A good result was obtained, but apparently something was done that ought not to be done; the oil had got into a "turbulent" state.

It appeared to him that the velocities given in the paper were very low compared with what were used in practice. He believed he was correct in saying that the highest velocity of Mexican oil in the authors' experiments was 1·5 ft. per second. The pump he had mentioned was designed for a velocity of 7·2 feet. In actual practice through a 14-inch pipe it did about 4·8 ft. per second, so that the velocities were much higher than those used in the experiments.

He also wished to point out that the experiments were made with a drawn tube, and that joints were specially avoided. He would like to know what happened when joints occurred, as they did in practice, every 20 ft. or 30 ft. He imagined they would add to the turbulence, because the two ends of the pipe did not come quite together, and therefore there was a ring of larger diameter that the

oil had to pass. Again, the pipe on which the experiments were made was carefully heated on the outside to keep it at an even temperature.

In practice it was impossible to heat the pipes outside, and keep everything just right. In actual practice, especially with a 14-inch pipe, the velocities varied from the circumference to the centre, particularly in cold weather, even when the oil had been heated.

There was a high velocity in the centre, i.e. more than the mean velocity through the pipe, and there was a very low velocity indeed in the oil in contact with the pipe. The diameter of the pipe was practically reduced through the cool oil strata adhering to the sides of the pipe. He was on the lookout for information, and would like to know how oil engineers were to calculate that. It must be dependent on the difference in temperature between the oil and the outside temperature, because it was well-known that in pumping through long, unburied, exposed pipe-lines in tropical countries during the daytime, when the pipe was exposed to the sun, nearly twice as much work could be done as at night-time, the pressure being kept constant. That was entirely due to the pipe being warmed, and the velocity of the oil being practically equal throughout the whole cross-section of the pipe. At night, when the outside of the pipe cooled, for practical purposes the diameter of the pipe was reduced; it was like pumping through a smaller pipe. If that change could be brought into anything like a formula, so that oil engineers could see what was required, it would be most valuable.

With regard to the question of the viscosity of Mexican oil, it was quite new to him that heating oil and then cooling, and the cooling and then heating, had a different effect. He thought that might bear commercially on the transport of oil in bulk. It was a question whether it was necessary to heat oil for some time, and to keep it hot while it was being discharged. Would it do as well if the oil was heated and allowed to cool, and discharged at a lower temperature, instead of keeping it hot all the while? There must be a point at which the two balanced, i.e. where the heating and the cooling down had decreased the viscosity so much that it was really not necessary to heat it again at all. That would have a very interesting bearing on the commercial handling of that oil in large quantities in bulk transport.

He hoped that on some future occasion the Institution would be favoured with another paper by the authors, in which they would enlighten the members a little more on those problems which occurred in actual practice, where engineers had to deal with pipes

that were cool outside, and that had joins, bends, valves, etc., affecting the flow of the oil.

Dr. Dunstan said it gave him great pleasure to join in the discussion; in the first place because he was a visitor, and, secondly, because one of the authors of the exceedingly interesting paper happened to be an old pupil of his; and one of the most pleasurable experiences in this world was to find an individual in whose early education one had had some part turning out such capital work. Speaking on the subject entirely as a theorist, he wished to draw attention to one or two points in connection with viscosity and the flash-point. The authors had pointed out that there was no law connecting the viscosity of mixtures with the proportions of the constituents. He had been confronted with that problem for some years, and could quite bear out the authors' assertion in that respect.

If, for example, a substance having the viscosity A was mixed with a substance having the viscosity B, A/B being the percentage composition, it never happened that the intermediate mixtures had the viscosity directly proportionate. All known mixtures could be divided into three classes. The bulk of them gave curves like fig. 12:

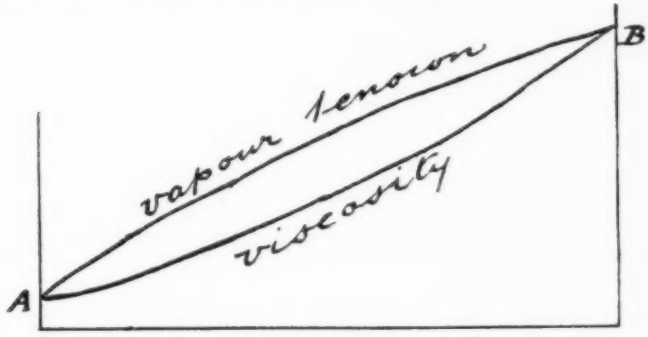

Fig. 12.

some few gave a curve exhibiting a minimum point; a few gave a curve exhibiting a maximum point; and it had been shown during the last fifteen years that the maximum point, speaking broadly, corresponded with the chemical combination. The minimum point seemed to be due to some peculiar chemical action between the components, but where there was no appreciable chemical action at all, the normal curve was obtained. It was pretty obvious from the run of the curve that the addition of quite a small amount to the

mobile component had relatively a very large effect in diminishing the viscosity of the more viscous components.

Professor Bingham, of Richmond College, U.S.A., had shown recently that the vapour-tension curve was about the reverse of the viscosity-curve. That was rather interesting, because the authors had shown that the flash-point was occasionally rather lower than that of the lower-flash component. If the vapour-tension curve obtained was higher than the medium vapour-tension curve, the higher tension meant more inflammable vapour being set free at a lower temperature.

He desired to ask the authors, with reference to the law connecting the viscosities, whether they had tried plotting the logarithm of viscosities against concentration, because both Professor Bingham, who rather favoured the reciprocal, and he (Dr. Dunstan) found that the logarithm of viscosity gave very nearly a lineal relation. With reference to the question of the lag, or the peculiar hysteresis effect, he had had the opportunity of examining some oils which

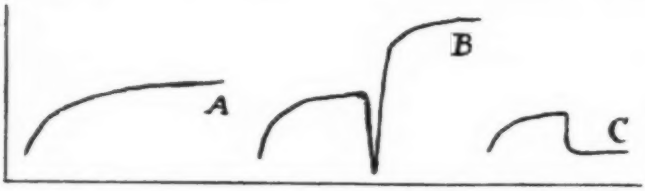

FIG. 13.

showed that phenomenon. He had not had time to make elaborate notes, but had brought with him one or two interesting curves showing the effect on the viscosity of the previous history of an oil, and of the different thermal changes to which it had been subjected.

In fig. 13 the curve A is that of a fuel oil, made in the laboratory. It was not really orthodox fuel oil, because its flash-point was lower, i.e. 140°. In the course of five or ten days it showed the gradually increasing viscosity to which the authors had referred; then the increase ended, and a permanent viscosity was obtained, probably due to the fading away of the thermal change caused in the preparation of the oil. The viscosities were taken at 25° C. constant temperature.

The curve B, made to the same scale, is that of a rather more viscous oil. The viscosity increased for a time, then the oil was heated to 60° C. for an hour, causing a fall in viscosity of about 5 %.

Then the sample was immersed in ice for three hours, and the viscosity rose accordingly. The queer thing was that two or three days afterwards the hysteresis was most beautifully shown, for the viscosity had still risen slightly.

Lastly an oil, C, was heated for an hour, and after three days and a half it was back again to the original value. It was then heated for several hours to the temperature of boiling water, but the reduction of viscosity showed hysteresis in continuing for some days, after which the curve tailed off into a constant figure.

With regard to the actual reason for all this, he desired to mention a few corresponding phenomena met with in the case of a jelly. An ordinary jelly could be made by adding water to gelatine in such a way and of such a concentration that the jelly would not set; the jelly was in a state of solution. But a jelly could be made so strong that it would set. If the jelly was heated overlong, according to domestic information, it would not set. If the same jelly was mashed with a spoon, it became liquid or semi-liquid. All those facts in connection with jellies could be observed with oils of that nature. With great diffidence he therefore suggested, as a possible explanation, that they were really dealing with colloidal phenomena.

Mr. E. Lawson Lomax, before passing on to the chemical side of the subject, said he desired to ask whether the authors had ever thought of using a pressure-cylinder, in which the oil could be stored under pressure, and could be delivered through the pipe under constant pressure for the experiment, instead of by means of pumps. In that manner they would do away with the heating of the oil due to the work of the pump, and it would be kept at a constant pressure.

With regard to the question of the mixture of two oils having a lower flash-point than either of the original constituents, he would like to know whether that applied to oils of the same origin or whether it applied to oils of different origin. It had some bearing on the fact that cases had been known in which tank-steamers had been loaded with oil from different tanks, the oil having the same specification in regard to flash-point before loading; but on testing the mixed oil after it had been loaded into the tank-steamers the flash-point had been found to be much lower.

With regard to the method of taking the flash-points of the oils, the authors had shown that it was most important, in taking the flash-points, if it was desired to obtain concordant results, to see that the oil-cup was filled to exactly the right height. The flash-point depended to a great extent on the saturation of the

supernatant air above the oil with oil-vapour, and until that reached a certain concentration no flash would take place. Naturally, if the height of the oil was lowered or raised, there would be more or less air requiring saturation, and he thought the flash-point might be affected in that way.

With regard to the question of the hysteresis of the oils, he thought the President had hit upon the explanation of it in his Treatise on Petroleum, vol. i, page 217, in which he remarked that the mixtures of paraffins and asphalts in oil took a long time to separate out, and that definite conditions for testing the oils were therefore difficult to obtain. That was shown in one of the experiments given in the present tables, in which the authors took a mixture of two parts of Scotch shale and one of Mexican oil, which were kept at the same temperature for several days. On samples for testing being taken from different heights, that from no. 3 exhibited a much higher viscosity than the bottom sample. This was probably due to the separation of paraffins, which, being of a crystalline nature, would cause the oil drawn from this position to flow very slowly through the viscometer; whereas the lower portion, consisting of asphaltic bodies of a non-crystalline nature, would flow through much more rapidly, the size of the particles not being so great. He thought that was also shown by the fact that the oils, after developing abnormal viscosity by the action of cold, lost it again on heating, and only after a time did the high viscosity return.

Mr. W. F. Higgins, in reply, said that nearly all the remarks which had been made referred to the question of hysteresis, and the answers could all more or less be summed up by saying that the work was in a very elementary stage. Very little opportunity had been afforded at the Laboratory of carrying the work through to any extent. On looking up the subject a couple of years ago he found practically no references at all to any results having been recorded.

The fact that a large amount of work had been done, but had not been recorded, was of great interest, but at the same time he felt that in the interests of science it was very desirable that results should be put on record, in order that they might be discussed from a much more general point of view. The work naturally took a very great deal of time. In order to get the effects mentioned in the paper the oils had been allowed to stand for many days (in some cases the experiments lasted for a couple of hundred days), and on this account it was hardly possible to collect together a large amount of information regarding any one series of changes in the time then available. The

results referred to by Mr. Hackford were most interesting, and he would like to have an opportunity of examining them in detail if possible.

In connection with the question of hysteresis raised by Dr. Beilby, one rather interesting case occurred in regard to an entirely different subject. Some paraffin oil was used in an oil-bath in which it was desired to obtain low temperatures. Ordinary paraffin oil was more or less objectionable from the point of view of smell, and it was considered that medicinal paraffin, which was presumably a very highly refined paraffin, and in consequence rather purer chemically, might have certain advantages. On experiment it was found that that medicinal paraffin oil showed a very marked tendency to the hysteresis effect, in distinction to the ordinary paraffin oil of commerce: this was rather the opposite of what one would imagine if it was merely a question of the mixtures of oils and the formation of jellies. One imagined that the medicinal paraffin was a fairly pure chemical substance, and therefore should show the effect to a much less marked extent than ordinary commercial paraffin, which necessarily consisted of a large number of components. This observation was made in a different connection altogether, but it had some bearing on the subject, and was worthy of mention.

Dr. Beilby's remarks with regard to gelatinisation were very interesting. Undoubtedly that work required carrying on, but personally he was not a chemist, and the work had been attacked from the physical point of view. He was afraid, therefore, he was not in a position to do justice to the discussion from the chemical point of view.

Dr. Cadman had referred to the flash-point observations, and to Professor Dixon's work regarding agitation of the surface. The question of the agitation was dealt with in the case of the experiments with the large flash-point apparatus. A definite experiment was made in which the stirring of the oil was stopped, to find out whether it had any appreciable effect on the flash-point, and he recorded the fact that, when the stirring was stopped, there was a distinct raising of the flash-point. In dealing with a large quantity of oil like that, some stirring must be adopted, in order to maintain an even temperature, but it was purposely arranged that the stirring was not sufficient to break up the surface. It was a gentle agitation of the oil, not a vigorous stirring which by breaking up the surface would give rise to a rapid evolution of vapour, which naturally would have a very marked effect on the flash-point.

The question of ventilation was also dealt with to a certain extent. The questions of the level and the ventilation were bound up together.

It was simply a question of the relative amount of vapour present, and the difference of temperature between the oil and the lowest temperature at which sufficient vapour was evolved.

Some interesting remarks had also been made with regard to the nature of the flash obtained. A few details were given in the paper with regard to the nature of the flash. If the flash occurred at a low temperature, it was always observed that the flash was very feeble. In some cases the flash just started, but was not propagated throughout the bulk of the vapour. In other cases, in which a long time had elapsed, or in which the temperature was raised above the ordinary low limit of temperature, there was a violent explosion. There was sufficient vapour mixed with the air to form an explosive mixture, and it ignited in quite an explosive manner, distinct from the ordinary flash obtained in the small apparatus, or in the large apparatus if the temperature was kept low. It was merely a question of the quantity of vapour which was allowed to accumulate in a given time.

Reference had also been made to the fact that the flash-point apparatus was purely an empirical type of apparatus, and in that connection it was absolutely essential to adhere rigidly to the rules laid down for making the determination. The question of flash-point determination had been discussed by Dr. Harker and himself in an earlier paper, and he thought there were some observations in that paper which had a distinct bearing on the present problem.

The question of practical economics connected with the heating of the oil previous to pumping, and the continuous heating during pumping, was rather interesting, but it was one which must be determined by practical people who had access to large plants, on which observations could be made on a practical scale. In such cases laboratory experiments were almost useless. They gave some indication of the general lines upon which the work should be done, but the main results must obviously be obtained from observations on a plant of commercial size.

He wished to conclude by saying how interested he had been to hear of the experiments referred to by Dr. Dunstan. The curves he had shown were a remarkable confirmation of the results he (Mr. Higgins) obtained in connection with Mexican oil. The other curves connecting viscosity with concentration were equally interesting.

He had nothing further to say, as unfortunately he was not in a position to reply to the discussion from the chemical side: his chief interest in the matter had been the determination of the constants from the physical point of view. The general theory of the whole

question of oils and their constitution was one of very great interest and its investigation should be carried much further than it had been at the present time.

Dr. R. T. Glazebrook, in reply, said he had been specially interested in the remarks made by Mr. Barringer, and he would be extremely obliged to that gentleman if he would send the authors the figures he had mentioned, because he felt certain that with those figures before them they could answer some of the conundrums he had put. So far as the actual practical flow of oil in pipes of varying temperatures was concerned, of course it was impossible to do anything unless one knew something about the distribution of the temperature within the pipes. He did not know what Mr. Pannell would say, but he fancied that, from the data given in the paper, the authors could prepare a very reasonable statement in regard to the amount of flow to be expected in the large pipes to which Mr. Barringer referred, provided some not impossible distribution of temperature was assumed inside, and calculations were made for cylindrical tubes of constant temperature. There were one, or two other practical matters of that kind that the authors could deal with, and if they could make the paper more useful by doing that work, they would be only too glad to do so. He had noticed that in reading the paper he omitted a section from the Report to the Admiralty dealing with the effect of bends and enlargements. It was only a short section, but he gathered from what Mr. Barringer had said that the addition of that section to the paper would be of value, and, with the permission of the Authorities, it should be added to the paper. He only desired to say, in conclusion, that his assistants and himself would be only too glad to be informed of any way in which they could make the paper of more real interest to practical men.

On the motion of **The President,** a very hearty vote of thanks was accorded to the authors for their valuable contribution to the proceedings of the Institution, and **Dr. Glazebrook** having briefly acknowledged the compliment, the meeting terminated.

Mr. F. Esling subsequently communicated the following remarks :—

Part II of Dr. Glazebrook's valuable paper deals with the Physical Properties of Oils : and under Section "*Tests on Mixtures of Oils*"—subhead (*b*) *Viscosity*—he discusses, not too fully, the effect of mixing oils of different viscosities, and points out that in cases where the two components have widely differing viscosities, mixtures do not give results following the "law of simple proportions." This fact has been general knowledge in the oil world for

a number of years, although it has not received any extensive recognition in oil literature. I had occasion early in 1912 to make a study of this effect in respect to the mixing of two lubricating oils of widely-differing viscosities. The one had a viscosity of 3,600 secs., and the other of 120 secs., tested by Redwood Viscometer No. 1 at 70° Fahr. These two oils were being used from time to time to compound various mixtures having viscosities in the region of 350, 450, 550 secs. etc. at 70° Fahr., and the assumption of the straight-line proportion resulted in serious discrepancies. With the object in view of overcoming this difficulty by the establishment of some simple method, I compounded various mixtures of these two oils, containing increasing quantities of the one component and correspondingly less of the other. These mixtures were carefully tested, as also were the original components, and the viscosities were plotted on a curve having percentages as abscissæ and viscosities as ordinates. From this curve the percentages of the two oils necessary to give a mixture of required specification could be read at a glance.

It might be argued that this curve had a very limited use, as being only serviceable when the two oils were exactly of viscosities 3,600 secs. and 120 secs., but this is not so: the curve can be used for mixtures of any two oils having viscosities intermediate between these two.

For example, suppose the thicker oil to have a viscosity of, say, 3,000 secs., and the thinner oil of 200 secs., and a mixture of these two is required having a viscosity of 500 secs. Then the proportions of these two are represented by the sections of the base line lying between the vertical co-ordinates of 3,000 secs. and 500 secs., and 200 secs. and 500 secs.: that portion between 3,000 secs. and 500 secs. representing the proportion of thin oil, and that between 200 secs. and 500 secs. representing the proportion of thick oil. Or, if these proportions are desired in percentages, the Euclid proposition dealing with similar triangles can be made use of by placing a scale divided into tens and hundreds with the zero anywhere convenient on the vertical co-ordinate corresponding to the 3,000 secs. viscosity oil and the hundred mark on that representing the 200 sec. oil, and where the vertical corresponding to the 500 sec. oil meets the scale the percentages are given directly. The curve is shown in the accompanying diagram, fig. 14.

In the discussion of Dr. Glazebrook's paper, Dr. Dunstan referred to the viscosity curves of mixed oils, and suggested a law involving the logarithms of the viscosities of mixtures. These, he said, should approximate to a straight-line law. This statement I have

the greatest pleasure in confirming, although from my results I find a slight variation where the percentage of thick oil predominates. From the accompanying table and diagram it will be seen that in the higher part of my curve representing mixtures containing between 90 % and 100 % of thick oil, tan θ, the slope of the logarithm curve, is at its steepest part, tan θ in this case having an average of 0·02775, whilst between the points representing 75 % to 90 % of the thick oil, tan θ = 0·01527, not so steep: and below this point the curve is almost a perfect straight line, tan θ being equal to 0·01299.

These differences may be due to experimental error, or there may be some internal force at work in the thick and only slightly diluted

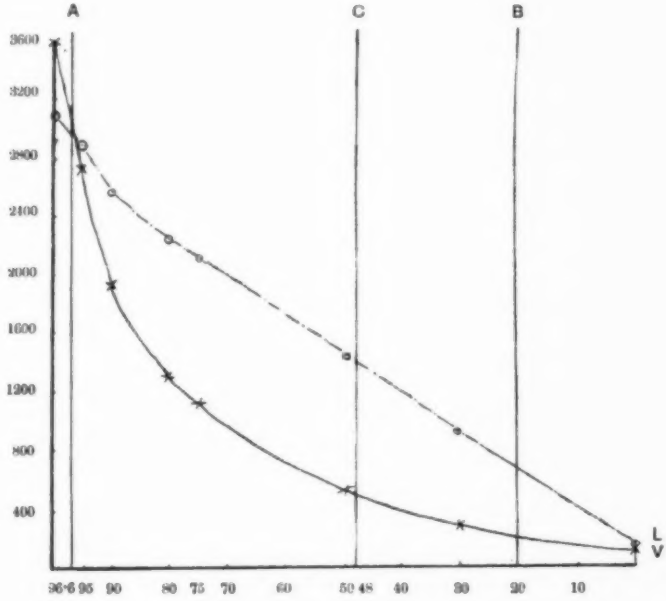

FIG. 14. Viscosity and logarithm curves for mixtures of oils between 3600 and 120 seconds on the Redwood viscometer no. 1 at 70° Fahr., with the method of calculating the percentage of any two oils within that range, requisite for a mixture of given viscosity: as example:—

A, oil of 3000 secs.: B, oil of 200 secs.: C, desired mixture of 500 secs. Inversely, BC/AC = 28/48·6 (on base line) = 36·5 (thick) /63·5 (thin).

Mixture.	Per cent. Thick Oil.	Per cent. Thin Oil.	Viscosity in Secs. Redwood No. 1 @ 70° F.	Logarithms of Viscosities.	Differences.	Differences per *one* per cent.	Tan θ, i.e. Slope of Logarithm Curve.	Over a Range of
1	100	0	3,600	3·55630				
					0·12173	0·02435		
2	95	5	2,720	3·43457			0·02775	10 %
					0·15582	0·03116		
3	90	10	1,900	3·27875				
					0·16148	0·01615		
4	80	20	1,310	3·11727			0·01527	15 %
					0·07195	0·01439		
5	75	25	1,110	3·04532				
					0·32104	0·01284		
6	50	50	530	2·72428				
					0·27712	0·01386	0·01299	75 %
7	30	70	280	2·44716				
					0·36798	0·01227		
8	0	100	120	2·07918				

oil which is retarding the viscosity: this may to some extent be akin to the property which causes the thickening of certain fuel oils when allowed to stand for some time, a property variously described as colloidal action, conglomeration or agglomeration of molecules.

Should the straight-line law of log. viscosities be generally accepted (and I see no reason why it should not be), the following formula should represent the *law of mixture of oils.*

$$x = 100 \frac{\log C - \log A}{\log B - \log A}$$

where x = percentage of thick oil
C = Viscosity of required mixture
A = ,, ,, thin oil
B = ,, ,, thick oil,

the percentage of thin oil is of course the difference, $100 - x$; or is represented by y in the formula

$$y = 100 \frac{\log B - \log C}{\log B - \log A}$$

or as a ratio of the two components:

$$\frac{x}{y} = \frac{\log C - \log A}{\log B - \log C}$$

On this **Mr. Higgins** wrote as follows:—

The method employed by Mr. Esling for determining the viscosity of a mixture of oils from a knowledge of the viscosities of its components would follow if the logarithmic law of mixtures were true for all oils.

This is not actually the case as is shown both by Mr. Esling's figures and by the results obtained in the course of the investigation dealt with in the paper. The method described is undoubtedly of value in commercial work for oils of similar nature, but cannot be relied upon for all oils, irrespective of their nature and origin.

W. F. H.

The following illustrations, Figs. 15 and 16 were not prepared in time for insertion in the text of the paper.—Ed.

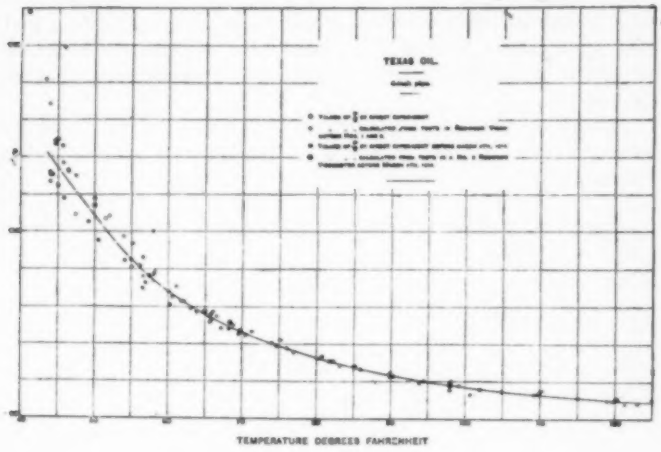
TEXAS OIL.
TEMPERATURE DEGREES FAHRENHEIT

FIG. 15.

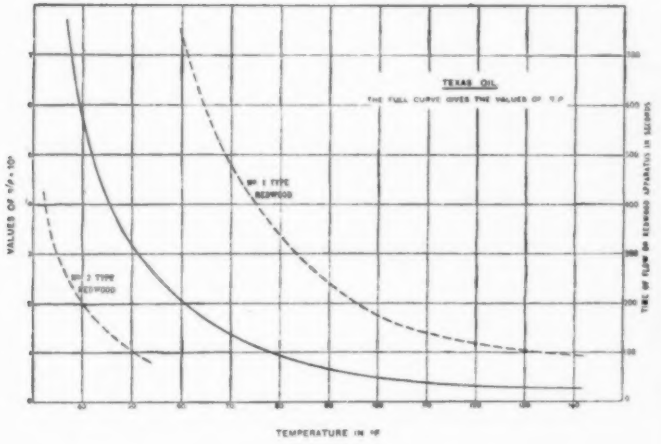
TEXAS OIL.
TEMPERATURE IN °F

FIG. 16.